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ENVIRONMENTAL AND ECONOMIC ASPECTS OF REFUSE DISPOSAL FROM ILLINOIS UNDERGROUND COAL MINING

(U. S. Department of Energy
Contract No. EW-78-X-21-5209)

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Preface

This document discusses past, present and future environmental aspects associated with coal mine refuse disposal, particularly from underground mines in Illinois. Current disposal practices have been strongly influenced by recent state and federal regulations that control such methods and prohibit on and off-site pollution from refuse sites. To understand the evolution of these regulations and the consequent changes in methods of refuse disposal, a historical perspective is provided on past trends in coal mining in Illinois, disposal practices, and impacts of refuse on air, land and water resources. The continuing problems associated with disposal sites abandoned prior to regulatory legislation are also reviewed.

Public concern over the adverse impacts of past refuse disposal practices resulted in passage of stringent restrictions. Although pollutional impacts from current disposal sites are eliminated by regulatory standards, there remains, however, problems of reduced land capability and productivity, and lowered property values and tax revenues from reclaimed sites. The costs associated with current and future refuse disposal are herein examined, as are the acreages and monetary values to be affected by future disposal, within the framework of current regulations. This examination of land values associated with disposal areas has particular relevance in Illinois where increased coal production is anticipated while the protection of agricultural land productivity is gaining increasing importance. Finally, alternatives to current refuse disposal techniques that address these considerations are discussed and evaluated.

Acknowledgements

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History

Coal was first recorded in Illinois by explorers in the late 1600's (Andros 1915). Small amounts of coal from outcrops along river bluffs and from shallow seams were used primarily for blacksmithing and domestic heating. Commercial shipment of Illinois coal began in 1810 when coal was sent by river from Murphysboro to New Orleans. Commercial production (6,000 tons) in Illinois was first recorded in 1833 (Andros 1915).

The increasing number of coal-burning locomotives and the continued development of Illinois cities and industries brought a rising demand for coal. During the Civil War coal production in Illinois began to increase with the rapidly expanding railroad system.

During the period before World War I coal became the predominant energy source in America. By the end of the war, Illinois coal production reached an all-time annual high of 90 million tons (Figure 1)(Illinois Department of Mines and Minerals 1918). Although small, unmechanized coal mines were still common in the post war years, many mines began replacing hand labor with machines (Sibley 1965).

Between 1919 and 1940, the number of large underground mines in Illinois declined from 370 to 139 (Illinois Department of Mines and Minerals 1918, 1975). The economic depression during this period undoubtedly contributed to the decrease, but other factors were important. These included 1) labor union conflicts, 2) overproduction, 3) differential labor costs between Illinois mines and mines in western Kentucky and Appalachian coal fields, 4) increased costs of mechanization, 5) competition from surface mines, and 6) development of substitute fuels (Brown and Webb 1941, Sibley 1965). In spite of these problems, some new mines opened during this period and the trend toward mechanization continued.

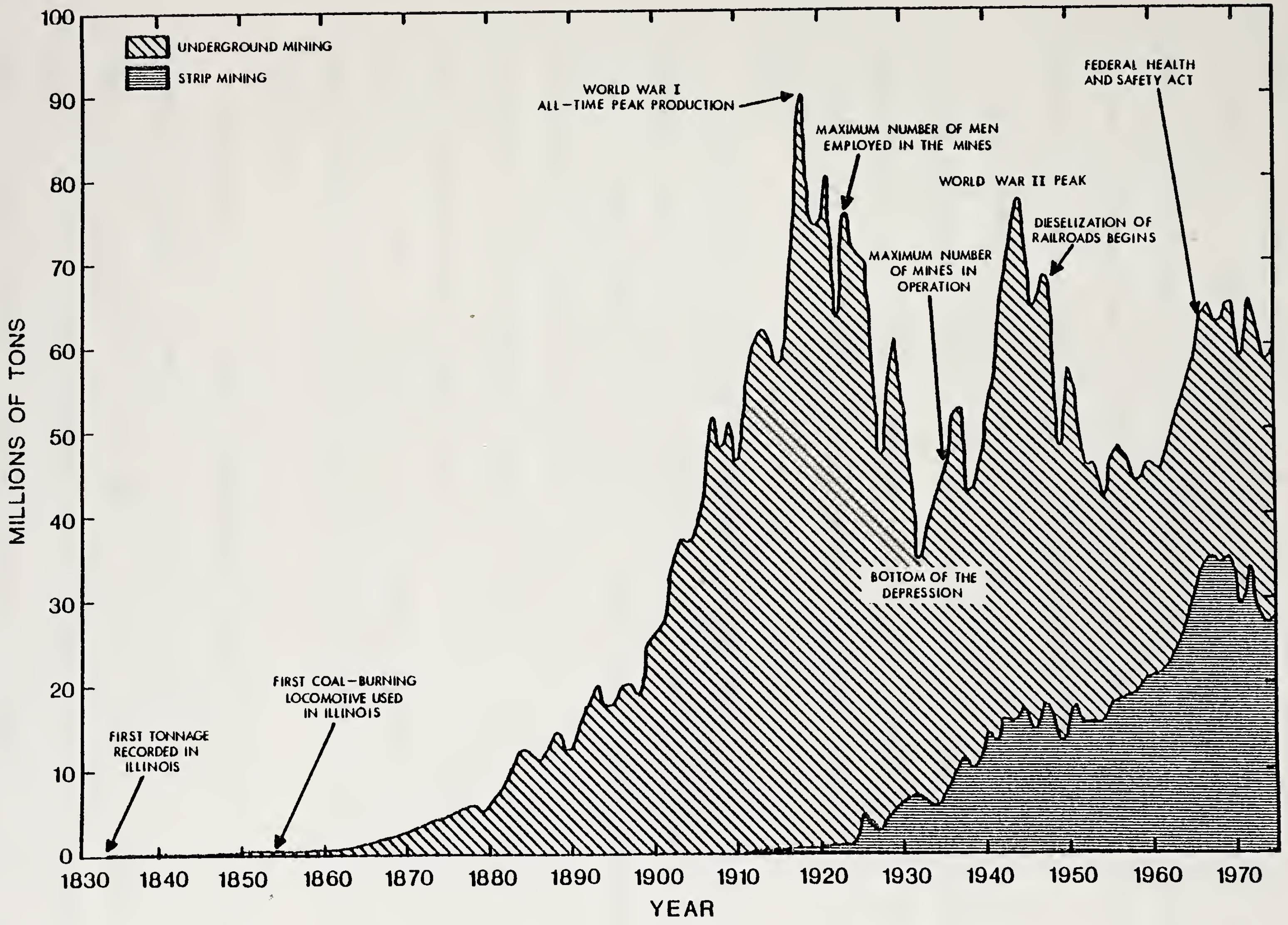

Figure 1. Coal production by underground and surface mines in Illinois from 1830 to 1975. (Carter et al. 1974).

In fact, by 1941 the only large mines operating were those which had increased mining efficiency through mechanization (Illinois Department of Mines and Minerals 1944).

Production from underground coal mines declined quickly in some areas with the advent of surface mining. Only 5 percent of Illinois' coal was surface-mined in 1925; by 1939, the proportion had increased to 24 percent (Illinois Department of Mines and Minerals 1939).

Coal production rose sharply during World War II, and in 1944 Illinois produced 77.4 million tons (Figure 1) (Illinois Department of Mines and Minerals 1944). However, production dropped quickly when the war ended and oil and natural gas gained a prominent role in the energy market.

Illinois coal production expanded during most of the 1960's but has declined since 1972 (Illinois Department of Mines and Minerals 1978). Clean air and competition from nuclear power may have been responsible for the decline (Simon and Malhotra 1976). In 1977, Illinois produced 53.9 million tons of coal of which 29.6 million tons, or 55 percent, came from underground mines (Figure 2) (Illinois Department of Mines and Minerals 1978). Although a prolonged strike occurred in 1977 underground production was not far below the 1976 total of 30.9 million tons (Table 1).

Using the 1977 Illinois underground production total and assuming an annual increase in demand of 4 percent, as suggested by Malhotra and Simon (1975), production of Illinois coal from underground mines would reach 59.8 million tons by 1995. This projected production estimate is close to the 58.0 million tons which can be estimated by adding tonnage increase predicted (Nielsen 1979) to the 1977 production and assuming that mines opened befor 1961 would not be operating in 1995 (Table 1) (Figure 3).

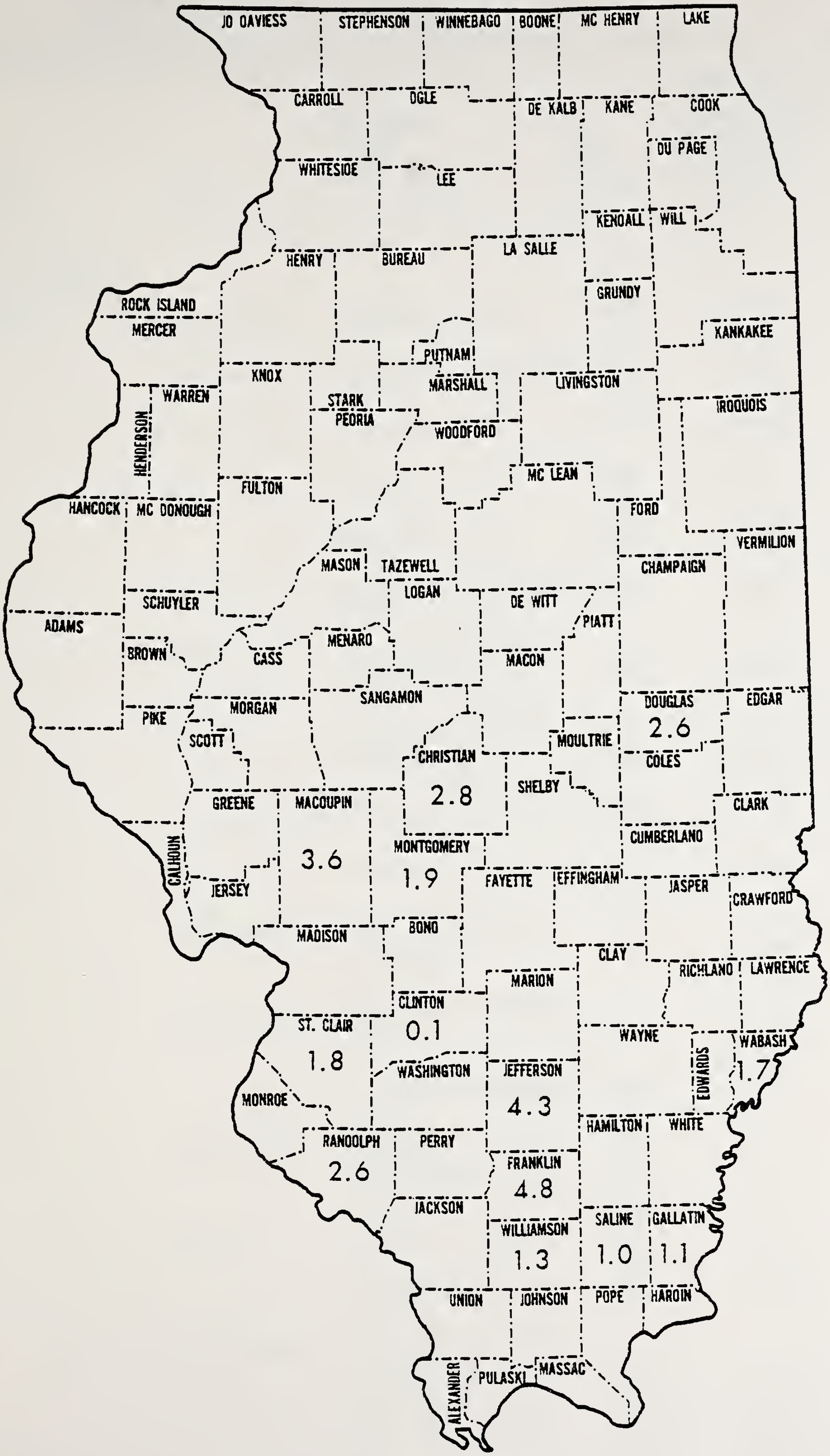

Figure 2. Annual coal production (millions of tons) from underground mines in Illinois counties for 1977 (Illinois Department of Mines and Minerals 1978).

Table 1. Annual production of underground mines in Illinois as of 1977 and 1995.

Status	County	Company and Mine Name	Year Opened	1977 Annual Production[1] (millions of tons)	1995 Annual Production[2] (millions of tons)
Mine Closing or Production Stable	Christian	Peabody, #10	1952	2.81	0
	Douglas	Ziegler, Murdock	1946	1.33	0
	Franklin	Old Ben, #21	1960	1.47	0
		Old Ben, #24	1965	1.75	1.75
		Old Ben, #26	1968	1.16	1.16
	Gallatin	Peabody, Eagle#2	1969	1.08	1.08
	Jefferson	Freeman United, Orient #3	1951	1.44	0
		Freeman United, Orient #6	1968	1.30	1.30
		Inland Steel, #1	1966	1.59	1.59
	Macoupin	Monterey, #1	1970	2.52	2.52
	Montgomery	Consolidation, Hillsboro	1964	1.85	1.85
	Randolph	Peabody, Baldwin #1	1972	1.68	1.68
		Ziegler, Spartan	1952	0.61	0
	St. Clair	Peabody, River King U/G	1970	1.78	1.78
	Saline	Sahara, #20	1970	0.50	0.50
		Sahara, #21	1971	0.47	0.47
	Williamson	Freeman United, Orient #4	1952	0.84	0
		Harrisburg, #1	1949	0.08	0
		Ziegler, #4	1943	0.40	0

Table 1. Continued.

Status	County	Company and Mine Name	Year Opened	1977 Annual Production[1] (millions of tons)	1995 Annual Production[2] (millions of tons)
Expanding Production	Clinton	Monterey, #2	1977	0.10	3.60
	Douglas	Ziegler, #5	1973	1.35	2.20
	Franklin	Old Ben, #25	1977	0.38	4.00*
	Macoupin	Freeman United, Crown 2	1976	1.10	2.40
	Randolph	Ziegler, #11	1975	0.28	1.50
	Wabash	Amax, Wabash	1973	1.72	3.60
New Mine	Edwards	Atlantic Ritchfield	1983	0	1.60
	Franklin	Old Ben, #27	1979	0	*
	Hamilton	Inland Steel, #2	1979	0	2.50
	Logan	Shell Oil, Niantic Annex	1982	0	2.50
	Macoupin	Freeman United, Crown 3	1981	0	2.00
	St. Clair	Peabody, Baldwin #2	1978	0	1.30
		Peabody, Baldwin #3	1979	0	1.30
		Peabody, Baldwin #4	1980	0	1.30
	Saline	Kennelli's Energies	1979	0	1.20
		Kerr-McGee	1983	0	2.50
	Williamson	Morris, #5	1978	0	1.00
		Morris, #6	1978	0	1.00

Table 1. Continued.

Status	County	Company and Mine Name	Year Opened	1977 Annual Production[1] (millions of tons)	1995 Annual Production[2] (millions of tons)
New Mine (continued)	Williamson (cont.)	Morris, #7	1978	0	0.60
		Ziegler, #6	1979	0	2.00
	Unnamed	Amax	1982	0	2.10
		NICOR	1980	0	2.00

[1] Source: Illinois Department of Mines and Minerals (1978).

[2] It is assumed that mines opened before 1961 will be closed by 1995 and that other mines not expanding will maintain 1977 production levels through 1995. Estimates of future production were taken from Nielson (1979).

*Future production estimates for the Old Ben #27 mine are listed in combination with production estimates for Old Ben #25. These mines share a preparation plant.

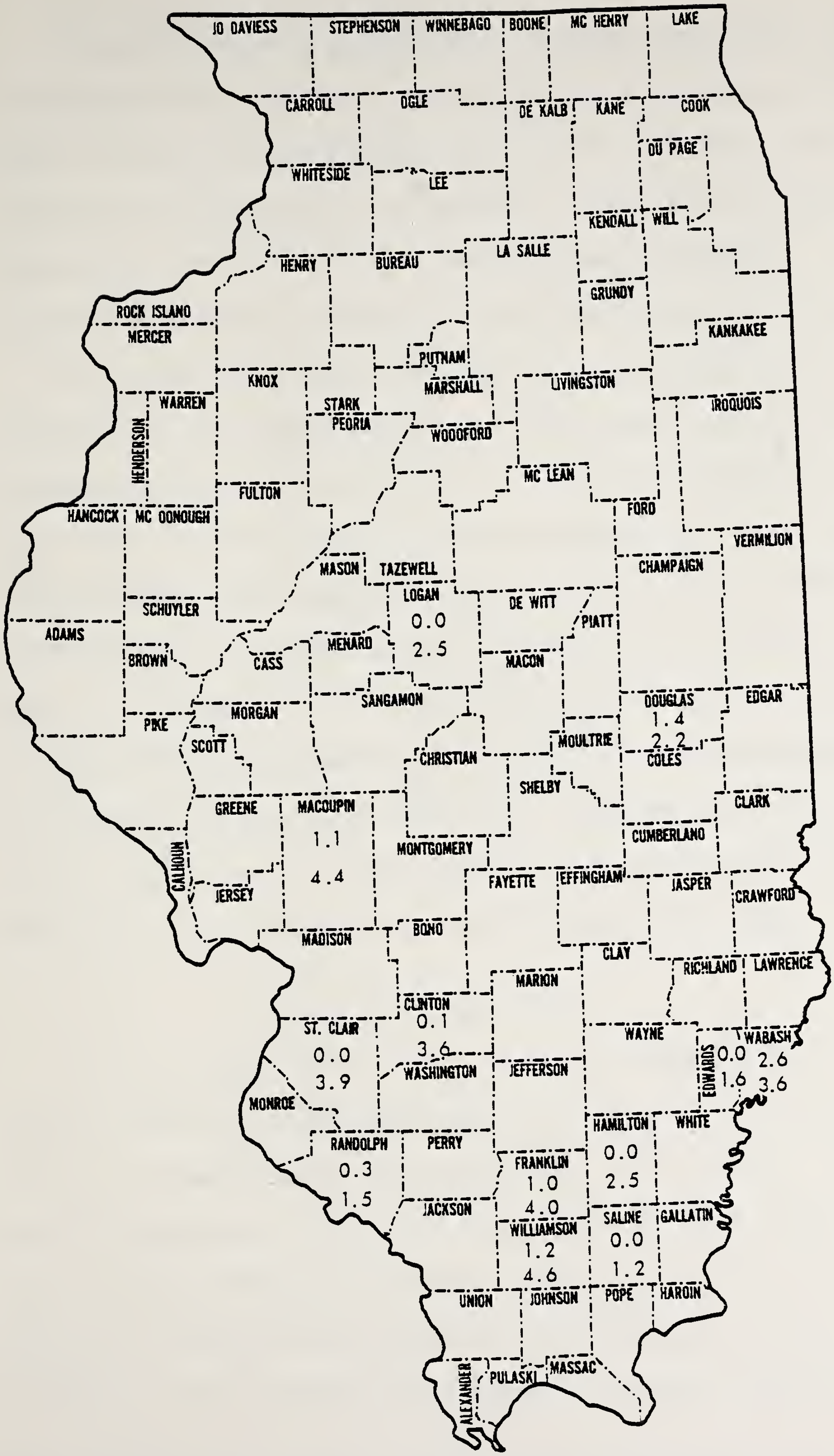

Figure 3. Present-1977 (upper number) and future-1995 (lower number) production (millions of tons) of new or expanding underground coal mines in Illinois counties (Illinois Department of Mines and Minerals 1978, Nielsen 1979).

Increased deep mine production in Illinois would result from new mine production and expansion of existing mines; however, closing of some existing mines would partially offset the increase. Of the 25 underground mines active in 13 counties in 1977, 4 to 6 mines can be expected to close by 1995 as minable reserves are depleted. Conversely, more than 10 new mines may open in this time (Figure 4) (Nielsen 1979).

In view of the unstable and uncertain coal market conditions as influenced by new Federal reclamation requirements and air quality standards, predicting mine openings or closings and production figures is a tenuous exercise even for mine management. Illinois' underground mine production may be approximately 60 million tons by 1995 but it could range widely depending upon 1) changes in air pollution regulations, 2) inroads into Illinois markets by western coal, 3) the proportion of energy provided by nuclear, gas, and oil, and 4) regulations of mining by government (Malhotra and Simon 1976). However, one aspect is certain, as coal production in Illinois increases land utilized for both preparation plant facilities and associated refuse disposal will also increase.

Current Coal Preparation*

Coal preparation involves the mechanical cleaning and sizing of coal for the purpose of providing a more uniform product with higher caloric value, and lower moisture, ash and pyritic sulfur content. For past and much of present coal mining such preparation has been minimal. Handpicking and screening provided coal of adequate quality for most consumers. Advanced mining practices including the utilization of less discriminate continuous mining machines has resulted in raw coal containing a greater

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*Material for this section has been summarized by Lihach (1979).

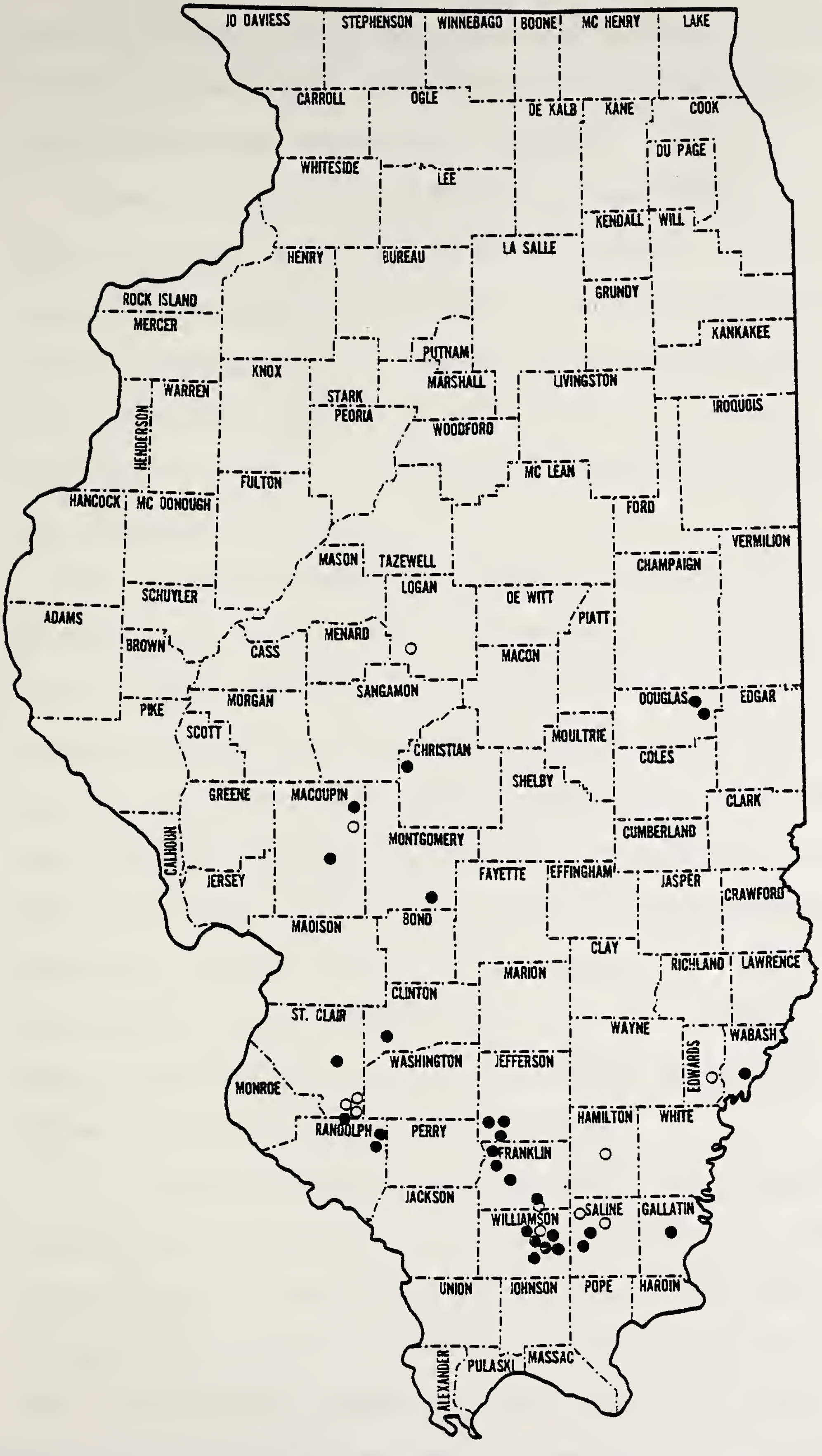


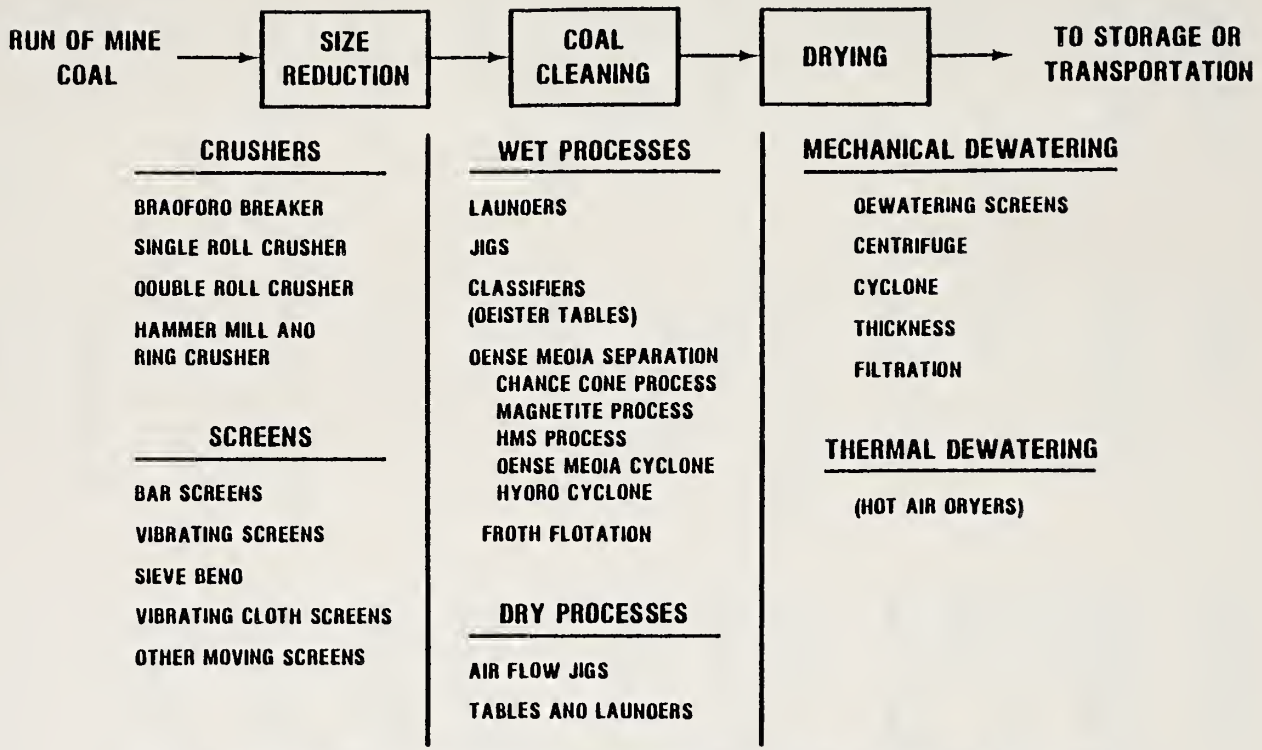
Figure 4. Location of active (dots) and planned (circles) underground coal mines in Illinois as of 1978 (Nielsen 1979).

percentage of roof, shale, rock, and floor materials. In addition, environmental restrictions on the burning of coal have generated increased interest and need for coal cleaning.

Increased cleaning provides coal that has higher BTU values, is lighter and burns cleaner. Up to 15 to 35 percent of raw coal mined is waste; consequently its preparation can lower shipping costs. Cleaning can remove up to 65 percent of the ash, which can foul boiler operations, and up to 30 to 35 percent of the sulfur content, permitting more consumers to meet emission requirements and lowering the cost of scrubber operations.

Coal preparation attempts to remove impurities (ash, sulfur, and moisture) and reduce BTU losses. To accommodate variations in run of mine coal conditions and contract specifications, a wide range of processes are utilized by preparation plants. Some plants merely screen and crush coal while others segregate coal into several sizes, each cleaned by a variety of methods most effective for each size. The general scheme of coal preparation includes three stages; size reduction, cleaning and drying, with a variety of processes and techniques available for each stage (Figure 5). Within Illinois, most modern preparation plants utilize jig washing, as well as froth flotation and heavy media washing (Table 2).

The initial treatment process utilized by most preparation plants involves size reduction of the raw coal by breakers and crushers to separate the coal from rock and debris. Some plants then clean unsized feeds while others separate coal into different sizes via screens and clean each fraction separately. Modern preparation plants may handle up to three sizes: coarse, intermediate, and fine.



NOTE: ANY ONE OR MORE OF THE ABOVE CRUSHING, SCREENING, CLEANING AND DRYING DEVICES ARE USED IN VARIOUS PARTS OF PREPARATION PLANT DEPENDING ON THE EXTENT OF PREPARATION REQUIRED

Figure 5. Coal preparation processes and techniques (Tetra Tech 1976).

Table 2. Preparation plants utilized by Illinois mines which process deep mined coal.[1]

Name of Operator	Address	Type and Make of Installation
Freeman United Coal Mining, Crown II	Virden	Jig Plant
Freeman United Coal Mining, #3	Waltonville	Deduster, Heavy Media, Jig, Heavy Media and Froth Flotation
Freeman United Coal Mining, #4	Marion	Roberts & Schaefer Heavy Media
Freeman United Coal Mining, #6	Waltonville	Heavy Media Washed
Harrisburg Coal Co.	West Frankfort	Deister Tale
Inland Steel Coal Co.	Sesser	Modern Preparation Plant
Monterey Coal Co. #1	Carlinville	Baum Jig Type Preparation Plant
Monterey Coal Co. #2	Albers	Jig Plant
Old Ben Coal Co. #26	Sesser	Heavy Media Cyclones Froth Flotation, Mogul Jig
Old Ben Coal Co. #21	Sesser	Heavy Media Cyclones Froth Flotation, Mogul Jig
Old Ben Coal Co. #25	West Frankfort	Heavy Media Cyclones Froth Flotation, Mogul Jig
Old Ben Coal Co. #27	West Frankfort	Heavy Media Cyclones Froth Flotation, Mogul Jig
Peabody Coal Co. Eagle #2	Shawneetown	Cyclone Plant
Peabody Coal Co. #10	Pawnee	Allis Chalmer Vibrator
Peabody Coal Co. River King U/G	Freeburg	McNally-Pittsburg
Peabody Coal Co. Randolph Prep Plant	Marissa	Roberts and Schaefer Plant

Table 2. Continued.

Name of Operator	Address	Type and Make of Installation
Sahara Coal Co., #6, #20, #21	Harrisburg	Entire production washed at Central Washing Plant
Zeigler Coal Co. #2	Sparta	Roberts & Schaefer
Zeigler Coal Co. #4	Johnston City	McNally Jig Washer
Zeigler Coal Co., Murdock	Murdock	McNally #223 Washer

[1] From Illinois Department of Mines and Minerals 1978 Annual Coal, Oil and Gas Report.

All cleaning systems, or circuits, operate on physical principles, specifically gravity separation. As coal has a lower specific gravity than most of its impurities, the impurities separate out more quickly than coal. The larger or coarse coal is commonly cleaned by a device called a jig in which pulsating currents of water or air are injected up through the coal with less-dense coal rising to the top of the mixture and separating from the more-dense refuse.

Heavy-media vessels and heavy-media cyclones work under the same principle as the jig except a fluid medium containing an additive (such as magnetite) produces a medium with a density intermediate between coal and refuse. The cyclone has the added benefit of centrifugal action to separate the heavy from light particles.

Intermediate-size coal fractions may be cleaned by heavy-media cyclones, and by water cyclones and cleaning tables. Water cyclones, or hydrocyclones are essentially similar to heavy-media cyclones except that water is utilized as the separating medium. Cleaning tables are slightly tilted, ribbed vibrating surfaces across which a coal-water slurry is transported. As the slurry mixture moves across the table, the heavier refuse settles to the bottom of the table at a faster rate than the lighter coal fraction.

Fine-coal particles are the most difficult to clean due to the decrease in specific gravity differences as size decreases. As a result of coal processing, as much as 25 to 30 percent of the coal is reduced from coarse lumps to fine particles; these particles therefore represent an important resource that may often be discarded at many plants. Techniques to recover fines include froth flotation and oil

agglomeration. Froth flotation relies on surface properties instead of gravity to separate particles. Raw coal fines are treated with an oil-based collecting agent that adheres to the coal but not the refuse. The resultant mixture is fed into a froth flotation cell where mechanical agitation produces air bubbles to which the coal-oil particles adhere and rise to the surface in a froth, while the refuse remains in the slurry which is subsequently disposed of. Oil agglomeration also involves adding an oil-based liquid which adheres to the coal fines, but repels the refuse. Agitation of the mixture causes the oil-covered particles to coalesce into larger particles that can be separated out by flotation or screening.

After cleaning the coal needs to be dryed, to avoid BTU loss, higher transportation costs and freezing while in transit. Mechanical drying uses vibrating screens, centrifuges and filters to remove excess water. Thermal dewatering with fluidized-bed dryers may also be necessary to completely dry cleaned coal.

All of the above methods have their limitations and drawbacks. Certain sizes of refuse and coal have similar enough specific gravities to make separation difficult. However, the ultimate result of modern coal preparation is the production of cleaner coal but also larger quantities of refuse.

General Characteristics of Refuse

During 1973, 398 million tons of raw coal were processed in the United States. Approximately 289 million tons of cleaned coal and 109 million tons of refuse were produced; consequently, 27 percent of

the raw coal processed was discarded as waste. In Illinois during 1973, 62 million tons of raw coal cleaned yielded slightly over 14 million tons of refuse (Tables 3 and 4).

Coal refuse is usually divided into two fractions, gob (coarse refuse) and slurry (fine refuse), which differ in physical and chemical characteristics. Gob consists of rock or large-sized fragments (plus 20 mesh) which are denser than coal and are separated from the coal by gravity. The composition and texture of gob varies due to differences in mining technique, seam mined, type of coal preparation and disposal method. Coarse refuse contains varying precentages of coal, clay, shale and rock, and has a specific gravity lower than most soils. Due to its variable composition, gob exhibits varying degrees of compaction, is often highly unstable and extremely erodible with poor soil moisture retention characteristics.

Chemically, coarse refuse contains a high percentage of pyritic materials (1 to 10 percent), which upon weathering produce acidic conditions and associated high concentrations of metallic ions and soluble salts (Table 5). Elements of greatest abundance in coal refuse from the Illinois Basin include silicon, sulfur, aluminum, iron, sodium, potassium, calcium, and magnesium; phosphorus and titanium are present in significant quantities. Maganese, cobalt, nickel, copper, zinc, arsenic, selenium, yttrium, cadmium and lead are not abundant but occur in sufficient quantities to be of environmental concern (Wewerka et al. 1978)(Table 6).

Slurry or fine refuse consists of smaller particles (minus 20 mesh) of lower specific gravity than gob that remain in the fluid medium during and after coal washing. This fine particle refuse is usually disposed of in slurry form, transported by pipeline to a settling pond or dewatering

Table 3. Mechanical Cleaning at Bituminous Coal and Lignite Mines in 1973.[1]

State	Total production (10^3 t)	Number of cleaning plants	Raw Coal (10^3 t)	Cleaned coal (10^3 t)	Refuse (10^3 t)
Alabama	19,230	19	18,433	11,705	6,728
Alaska	694	1	70	50	20
Colorado	6,233	3	1,933	1,662	270
Illinois	61,572	36	62,386	48,091	14,295
Indiana	25,253	10	25,330	19,699	5,631
Kentucky (eastern)	73,966	33	30,359	22,264	8,095
Kentucky (western)	53,679	18	26.004	20,005	5,999
Ohio	45,783	17	20,799	14,588	6,211
Oklahoma	2,183	3	381	312	69
Pennsylvania	76,403	68	63,041	45,731	17,310
Tennessee	8,219	2	1,575	1,145	430
Utah	5,500	7	4,156	3,575	581
Virginia	33,961	32	26,559	17,696	8,863
Washington	3,270	2	4,460	3,262	1,198
West Virginia	115,448	124	107,520	75,672	31,848
Other states	60,344	7	4,639	3,460	1,179
Total	591,738	382	397,646	288,918	108,728

[1] Data from Westerstrom (1975).

Table 4. Clean Coal and Refuse as Percentages of Raw Coal and Refuse/Clean Coal Ratios for Appalachian and Eastern Interior Coals.[1]

	Clean coal as percent of raw coal	Refuse as percent of raw coal	Ratio of refuse to clean coal
Alabama	64	36	0.57
Illinois	77	23	0.30
Indiana	78	22	0.29
Kentucky (eastern)	73	27	0.36
Kentucky (western)	77	23	0.30
Ohio	75	25	0.33
Pennsylvania	73	27	0.38
Tennessee	73	27	0.38
Virginia	67	33	0.50
West Virginia	70	30	0.42
Average	73	27	0.38

---

[1] From Dvorak et al. (1977).

Table 5. Levels of pH, available phosphorus, and soluble salts in gob and slurry refuse associated with surface mining for coal in Illinois.[1]

	pH	P	Total Soluble Salts	Soluble			
				SO_4	Fe	Mn	Al
Gob (n=5):			mmhos/cm	ppm			
Range	2.4-3.0	5- 19	0.3-3.0	219.3-485.0	8.2-997.0	2.1-16.3	64.1-492.0
Median	2.9	12	1.7	315.0	44.0	2.7	201.6
Mean	2.8	12	1.5	335.4	223.8	6.5	210.6
SD	0.25	5.20	1.06	99.71	432.55	6.15	169.19
Slurry (n=17):							
Range	2.2-7.4	2-170	0.3-5.2	133.3-518.8	0.9-997.0	0.8-17.2	0.6-649.0
Median	3.0	10	2.4	397.5	19.7	5.5	93.6
Mean	3.7	22	2.6	355.3	245.2	6.7	161.0
SD	1.52	40.99	1.36	146.86	345.29	5.63	193.75

[1] Data from Haynes and Klimstra (1975).

Table 6. Trace element-mineral associations from analysis of Illinois basin coal refuse from two preparation plants.[1]

Mineral	Abundant Elements	Occasional Elements
Iron Sulfides		Tl, Mn, As, Cu
Clays	K, Mg, Ca, Fe, Ti	Li, Rb, Sr, Ba, Cl, Ta, Zr, Ce, La, Nd
Quartz		Li, Be, Na, Mg, Al, K, Ca, Fe, Ta
Oxides	Fe, Ti, Zr, O	Mn, V, Cr
Carbonates		None
Phosphates	Ca, Y, F	La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Th, U, Ba
Coal	S, O	Li, Na, Mg, Si, Al, K, Ca, Ti, Fe, V, Cr, Mn, Y, La, Ce, Nd, Sm, Eu, Cl

[1] From Wewerka et al. (1978).

impoundment. Slurry usually consists of varying amounts of sand, silt, clay, and coal; it generally has more uniform physical characteristics than gob (D'Antuono 1979). The small particle size of slurry as well as its uniform texture and lack of cohesiveness result in extreme instability and susceptibility to wind and water erosion. Chemically, slurry generally resembles gob and is characterized by low pH, high acidity and high conductivity with concentrations of soluble salts and metallic ions (Table 5).

Pre-Law Refuse Disposal

The inherent structural characteristics of refuse influenced past methods of disposal. Recent concern over the adverse environmental effects associated with the physical and chemical characteristics of refuse has prompted enactment of regulations that have altered and restricted methods of disposal. Prior to environmental regulations, gob and slurry were characteristically disposed of in the most economically feasible manner. Coarse refuse was deposited in the nearest convenient location while slurry may have been pumped to the nearest stream or low-lying area. Runoff and sedimentation from refuse areas were often uncontrolled. Over 3 billion tons of refuse have accumulated in the estimated 3,000 to 5,000 waste disposal areas in the United States; approximately half of these sites constitute safety, health, or environmental problems (National Academy of Science 1975). Approximately one fourth of the nation's coal refuse piles contain over 1 million cubic yards each; some accumulations are over 300 feet high and occupy over 100 acres (McNay 1971, National Academy of Sciences 1975). In Illinois, coarse refuse (estimated volume: 71 million cubic yards) sites range from scattered gob a few inches deep to conical or terraced piles more

than 200 feet high containing over 1 million cubic yards (Figure 6) (Nawrot et al. 1977). The simplest pre-law disposal methods resulted in dumping of refuse in mounds or down hillsides into valleys; slurry was sometimes pumped into waterways or hastily constructed impoundments. In addition to adverse environmental impacts, past refuse disposal techniques and engineering procedures contributed to the collapse of refuse embankments, exemplified by the 1972 Buffalo Creek disaster which claimed 125 lives in West Virginia (Schlick and Wahler 1976).

Terrestrial Impacts

Severe environmental problems were associated with pre-law methods of refuse disposal, including water and air pollution, reduced land use potential, and impaired aesthetic value. Many of these problems were the consequence of toxic materials in mine wastes. Unreclaimed coal refuse represents a harsh environment where natural invasion of vegetation or attempts to establish vegetative cover to aid in amelioration of adverse environmental effects are often limited by phytotoxic chemical conditions. Recently deposited refuse generally has a near neutral pH; however, weathering and breakdown of the non-pyritic portion of the refuse results in pH levels between 4.0 and 4.5, standard values for highly leached mineral soils with a clay fraction (Doubleday and Jones 1977, McGrath 1972). Oxidation of pyritic materials,usually in coal refuse in varying amounts, accelerates and further depresses the pH through leaching of sulfuric acid produced by chemical and biological reactions. The over-all equations for pyrite oxidation, which produce four equivalents of acid for each mole of pyrite present, are described by Singer and Stumm (1970):

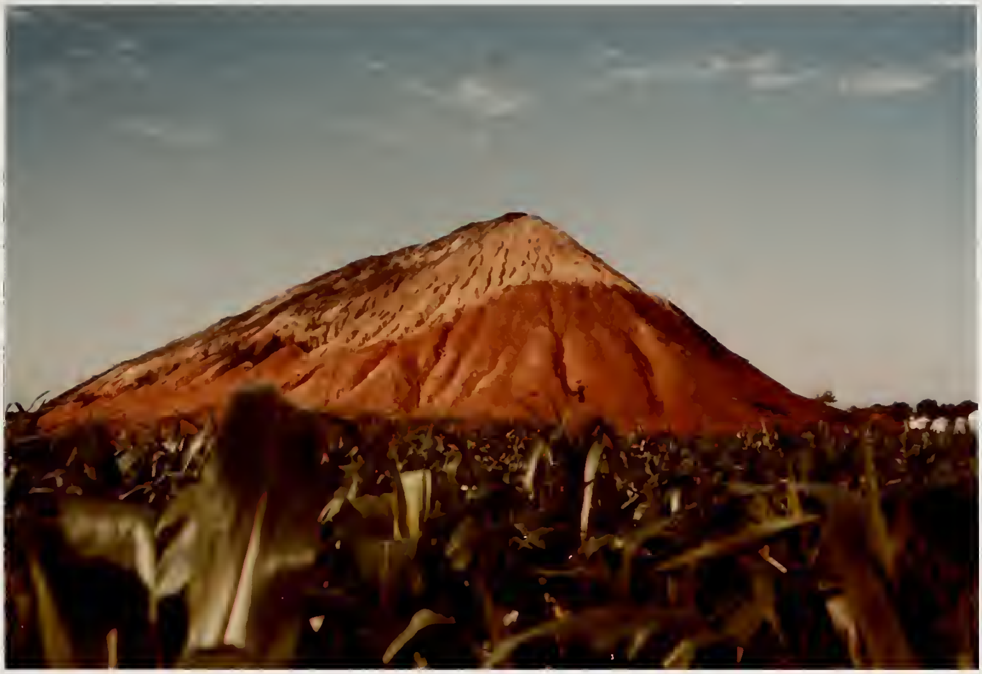


Figure 6. A large, pre-law gob pile located in agricultural land in northern Illinois.

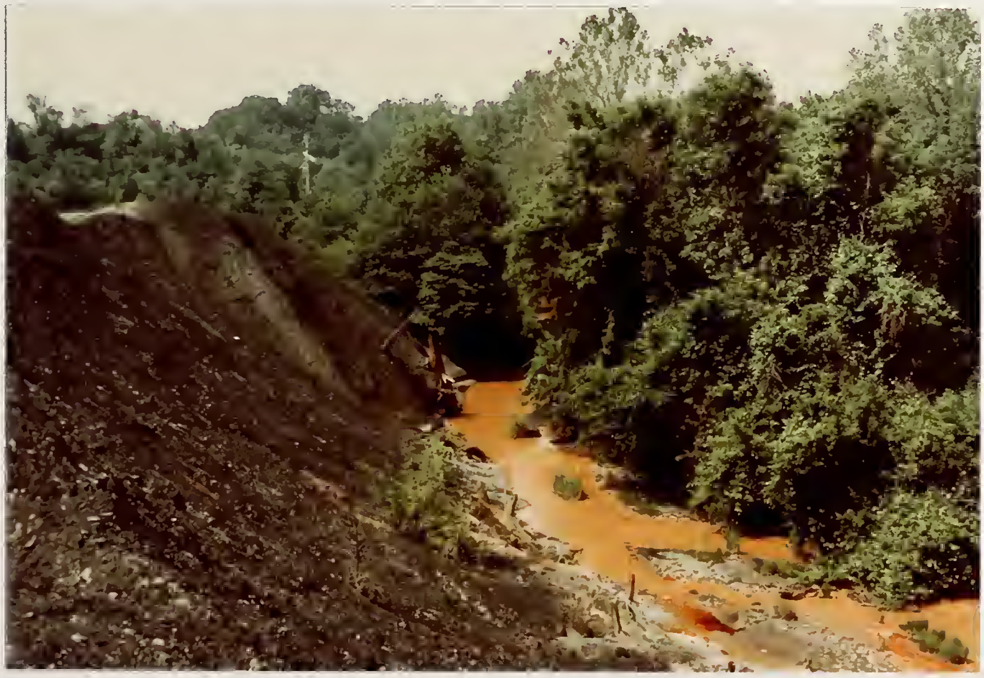


Figure 7. Acid mine drainage from an uncovered pre-law refuse embankment.

(1) $FeS_2(s) + 7/2\ O_2 + H_2O = Fe^{+2} + 2SO_4^{-2} + 2H^+$

(2) $Fe^{+2} + 1/4\ O_2 + H^+ = Fe^{+3} + 1/2\ H_2O$

(3) $Fe^{+3} + 3H_2O = Fe(OH)_3\ (s) + 3H^+$

(4) $FeS_2(s) + 14Fe^{+3} + 8H_2O = 15Fe^{+2} + 2SO_4^{-2} + 16H^+$

Oxidation of S_2 of pyrite to sulfate releases ferrous iron and acidity into water (1). Subsequently, dissolved ferrous iron loses an electron to form ferric iron (2), which hydrolizes to insoluble ferric hydroxide and releases three equivalents of acidity (3). Pyrite can also reduce ferric iron (4) releasing acidity and sulfate. Ferrous iron then re-enters the reaction cycle at equation (2); therefore, effective control measures must be directed toward the catalytic oxidation of ferrous iron. In addition, the rate of acid production can be accelerated by the activity of autotrophic iron-oxidizing bacteria (Silverman and Ehrlich 1964). The acid production rate of equation (2) is too slow in the absence of microbial activity to result in significant acid production; consequently, iron-oxidizing bacteria are essential to production of deleterious amounts of acid mine drainage.

In some refuse disposal sites, acid and acid-producing materials are quickly removed from the surface by weathering and leaching. However, many areas may be subject to a slower rate of oxidation and/or associated leaching so that highly acidic conditions persist for long periods (Richardson 1977).

The hydrogen ion concentration of soil solutions is designated as active acidity and its level is indicated by pH. Hydrogen and aluminum ions held on soil colloids are referred to as reserve or exchangeable acidity. Adsorbed metallic cations, as well as hydrogen and aluminum ions,

indirectly control the pH of soil and determine the amount of basic or acidic constituents necessary to cause a change in soil pH (Brady 1974).

Although pH is not a measure of total acidity in coal refuse, the adverse effects associated with low pH have been established. Phytotoxicity of refuse may not always be the result of high acidity alone, but rather a combination of high acidity and high concentrations of associated elements (Thompson 1971, Welsh and Hutnik 1972). Below a pH of 4.0, the increased solubility of iron, aluminum, manganese, and other potentially phytotoxic metallic ions results in higher soluble salt concentrations which may be toxic to most plants (Berg 1965, Brady 1974, Cummins et al. 1965, Richardson 1977). Wewerka et al. (1978), characterizing leachates from refuse from three coal processing plants in Illinois, revealed an inverse relationship between pH and amounts of various phytotoxic elements leached from refuse. In addition, some elements (aluminum, calcium, iron, magnesium) were released in relatively high absolute quantities. Other elements associated with coal refuse considered environmentally sensitive (cobalt, copper, nickle, zinc) although less abundant, were leached in high proportion to the total of each present. They concluded the single most important characteristic of high-sulfur refuse was its tendency to produce acidic leachates. In addition to low pH, high soluble salt concentrations, and phytotoxic metallic ion levels, much refuse exhibits deficient macro-nutrient levels. Although poor growth may be exhibited by vegetation growing on refuse, low nutrient availability rarely precludes vegetation invasion (Coalgate et al. 1973, Schramm 1966). However, vegetation established on refuse deficient in macro-nutrients may exhibit poor vegetative and root growth. Consequently, during periods of high temperature, drought, or severe erosion, minimal nutrient levels may indirectly result in localized vegetation failure on some disposal areas (Welsh and Hutnik 1972).

Illinois Lands Affected by Pre-Law Refuse Disposal

Illinois lands affected by past underground coal mining and refuse disposal were identified during 1975 to 1976 (Nawrot et al. 1977). A total of 55 counties contained almost 7,000 acres of affected land associated with 700 inactive mine sites. More than 80 percent of the affected acreage was located in 11 extensively mined counties. Gob refuse was estimated to contain over 71 million cubic yards of material, to cover 3,944 acres and to range in size from 0.1 to 323 acres. Over 50 percent of the acreage was located in Franklin, Christian, Saline, Williamson and Macoupin counties.

Slurry, associated with 38 inactive mine sites, accounted for 694 acres with sites ranging in size from 0.1 to 100 acres; over 60 percent was in Franklin, Williamson and Saline counties. Tipple sites (mine entries and support buildings and coal processing equipment) covered 813 acres, ranging in size from 0.1 to 51 acres at 192 sites. Over 70 percent of the inactive tipple site acreage was located in Franklin, Williamson, Saline, Macoupin, Montgomery and Perry counties.

Of the 700 inactive underground mine sites, 172 comprised 72 percent (4,980 acres) of the affected acreage. These sites, operated by major mining companies, reflected the trend from small, private individual operators to large, corporate mines of the present. Most of the larger affected areas resulted from major mining operations; and, although fewer in number, they occupied larger acreages, averaging 29 acres compared to 4 acres for private mines or small companies. More refuse and land disturbance was associated with these larger mines, as major mining companies were able to invest capital in above-ground washing and separating facilities, while smaller operators separated refuse from coal underground or sold unprocessed coal.

These affected acreages exhibited varying degrees of revegetation with herbs, shrubs and small trees comprising the predominant successional stage on gob refuse; however, 43 percent of gob refuse contained no vegetation. Over 47 percent of slurry areas were also barren. Only 25 percent of the tipple acreage was barren; most contained good vegetative cover.

Problem acreages were identified for some mines abandoned prior to 1972, when an act requiring the reclamation of inactive underground mine refuse became effective in Illinois. These problem acreages, containing potential and actual environmental problems such as severe erosion, siltation and acid runoff, comprised approximately 5,000 acres at 508 mine sites. Problem gob areas were characterized by severe gully erosion (2,706 acres), while 1,235 acres exhibited ril and/or sheet erosion (Figure 8). Slurry areas included 457 acres characterized by sheet and rill erosion, while the remaining 236 acres exhibited severe gully erosion (Figure 8). Of the 109 impoundments recorded at 89 mine sites, 36 covering 198 acres, were polluted and considered problem impoundments. Acid mine drainage from exposed refuse materials, from acid pools on refuse areas and from mine openings was identified at 343 sites in 40 counties.

Water Quality Impacts of Drainage from Mine Refuse

The preparation plant sites of abandoned surface and underground mines with associated refuse disposal areas and haulage roads are potential sources of mine-related water pollution. Drainage from abandoned mines may cause severe sedimentation, acidification and/or metal contamination of adjacent streams and rivers (Figure 7). Acid mine drainage is characterized by low pH, net acidity, high sulfate, and significant concentrations of aluminum, manganese, magnesium and calcium (Hill 1968). Drainage quality and quantity

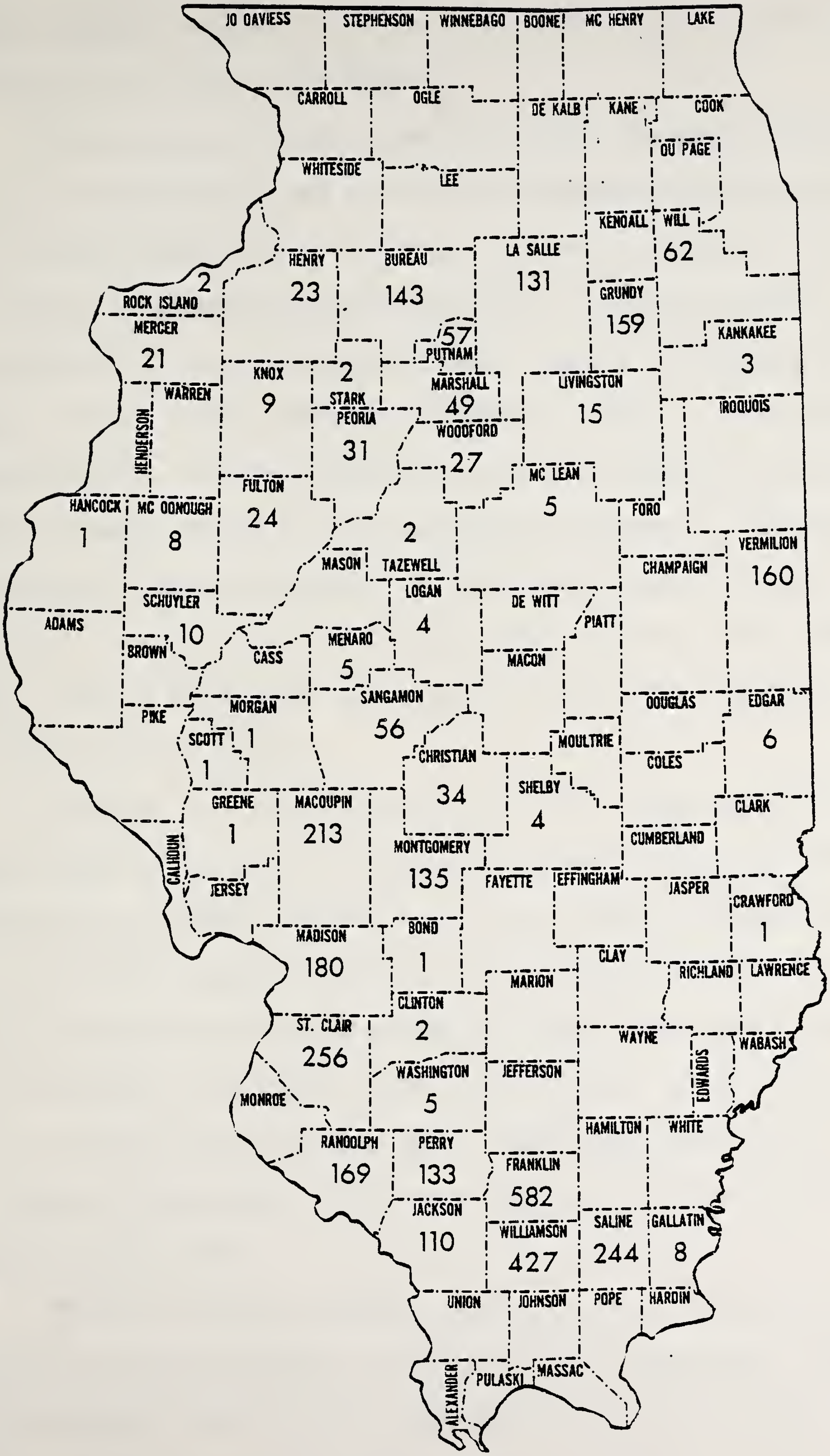


Figure 8. Problem acreages of refuse (gob and slurry) from abandoned underground coal mines in Illinois counties (Nawrot et al. 1977).

depend on properties of coal mined, mining method, reclamation, mine age, local geology, presence of bacteria associated with acid mine drainage, hydrology and climatic conditions.

Mine drainage affected rivers and streams have been identified through state-wide sampling by the Illinois Environmental Protection Agency (IEPA) to determine water quality for each Illinois river basin. Coal mining (surface and underground) was recognized as a possible source of non-point pollution with the following parameters commonly violating Illinois Pollution Control Board (IPCB) general use standards (Table 7); iron, sulfate, manganese, copper and pH. Of mine-related water quality violations for each segment or basin affected (Table 8), iron was the most frequently violated parameter, followed by copper, manganese, pH, dissolved oxygen, sulfate, lead and mercury. The majority of violations were associated within the Illinois, Ohio, and Big Muddy River basins which included the largest acreage of problem refuse disposal.

Schleuger (1975) previously reported that mine drainage had affected approximately 400 miles of streams and rivers in Illinois; 265 miles were affected to a degree that they were either devoid of aquatic life or could not continually support fish and other aquatic organisms. The acidic and highly mineralized waters draining from mine areas support relatively little aquatic life (Lackey 1939, Warner 1973). The acid and minerals also increase water treatment costs, reduce recreational uses, and corrode structures in the water (Goldberg and Powers 1972, Grim and Hill 1974, Scott and Hays 1975).

Erosion of refuse piles can degrade water by increasing turbidity, which limits photosynthesis and alters water temperatures, and by increasing sedimentation, which inhibits bottom-dwelling organisms (Hill 1968).

Table 7. Illinois Pollution Control Board mine effluent criteria and general standards for Illinois waters.

Constituent	General Standard mg/l	Mine Effluent Criteria mg/l
Ammonium nitrogen (as N)	1.5	5.0
Arsenic (total)	1.0	
Barium (total)	5.0	
Boron (total)	1.0	
Cadmium (total)	0.05	
Chloride	500	
Chromium (total hexavalent)	0.05	
Chromium (total trivalent)	1.0	
Copper (total)	0.02	
Cyanide	0.025	
Fluoride	1.4	8.0
Iron (total)	1.0	7.0
Lead (total)	0.1	1.0
Manganese (total)	1.0	
Mercury	0.0005	
Nickel (total)	1.0	
pH	6.5 - 9.0	5 - 10
Phenols	0.1	
Selenium (total)	1.0	
Silver (total)	0.005	
Sulfate	500	
Total dissolved solids	1000	50
Zinc	1.0	5.0

Table 8. Illinois Basin Segments with number of mine related water quality violations[1] and stream mileage affected by those violations (based on IEPA Water Quality Management Basin Plans, Phase I, Water Quality Data).

Basin/ Segment	Iron (1.0 mg/l)	Copper (0.02 mg/l)	Manganese (1.0 mg/l)	pH (6.5-9.0)	Dissolved Oxygen (5.0 mg/l)	Sulfate (500 mg/l)	Lead (0.1 mg/l)	Mercury (0.5 mg/l)	Stream Mileage With Violations
ILLINOIS									
A-02	1	-	-	-	-	-	2	-	53.25
A-03	3	-	-	-	-	-	1	-	68.75
A-04	10	3	3	-	-	1	2	-	196.50
A-06	4	-	-	-	-	-	-	-	87.50
B-01	3	5	-	-	-	-	3	1	84.75
B-02	5	6	-	-	-	-	6	-	92.50
B-03	1	1	-	-	-	-	-	-	37.50
B-04	2	1	-	-	-	-	-	-	23.25
B-05	9	2	1	-	-	-	-	1	196.50
B-06	5	1	-	-	-	-	-	-	162.50
Basin Totals	43	19	4	0	0	1	14	2	1003.00
OHIO									
A-01	1	-	-	-	-	-	-	-	5.00
A-02	4	2	1	-	-	3	-	-	23.75
A-03	5	3	3	4	3	3	-	-	51.25
A-04	5	1	2	5	1	2	-	-	39.25
A-05	1	-	-	1	1	-	-	1	26.25
B-02	3	2	-	3	1	-	-	1	36.00
B-03	7	2	1	2	1	-	-	-	53.75
Basin Totals	26	10	7	15	7	8	0	2	235.25

Basin/ Segment	Iron (1.0 mg/l)	Copper (0.02 mg/l)	Manganese (1.0 mg/l)	pH (6.5-9.0)	Dissolved Oxygen (5.0 mg/l)	Sulfate (500 mg/l)	Lead (0.1 mg/l)	Mercury (0.5 mg/l)	Stream Mileage With Violations
BIG MUDDY									
A-01	1	-	1	1	-	-	-	1	17.50
A-02	2	2	2	1	1	1	-	1	22.50
A-03	3	1	-	-	1	1	-	-	37.50
A-04	6	2	-	-	2	2	-	-	80.00
A-05	2	-	2	1	-	1	-	-	13.75
A-06	-	-	-	1	-	-	-	-	17.50
A-07	1	-	1	1	-	-	-	-	18.75
B-01	3	1	2	-	3	2	-	-	42.75
B-02	2	1	2	2	-	2	-	1	20.50
B-03	3	-	-	2	-	-	-	-	81.25
Basin Totals	23	7	10	9	7	9	0	3	352.00
MISSISSIPPI SOUTH CENTRAL									
A-01	-	1	-	-	-	-	-	-	8.75
A-02	4	-	-	-	2	-	-	-	38.75
A-03	4	-	2	-	1	-	-	-	38.75
A-04	2	-	1	-	-	-	-	-	26.00
B-01	5	-	4	-	-	-	-	4	151.00
Basin Totals	15	1	7	0	3	0	0	4	263.25

Basin/ Segment	Iron (1.0 mg/l)	Copper (0.02 mg/l)	Manganese (1.0 mg/l)	pH (6.5-9.0)	Dissolved Oxygen (5.0 mg/l)	Sulfate (500 mg/l)	Lead (0.1 mg/l)	Mercury (0.5 mg/l)	Stream Mileage With Violations
WABASH									
A-01	7	-	-	-	-	-	-	-	70.75
A-03	2	-	-	-	-	-	-	-	25.00
A-08	3	2	2	1	-	-	-	2	40.00
B-01	2	-	-	-	-	-	-	-	29.75
B-02	3	-	-	-	-	-	-	-	71.25
Basin Totals	17	2	2	1	0	0	0	2	236.75
KASKASKIA									
A-01	3	-	-	-	2	-	-	1	85.50
A-02	2	-	1	-	-	-	-	-	57.75
A-03	1	1	-	-	1	-	-	-	36.25
A-04	1	-	1	-	1	-	-	-	17.50
B-03	1	-	-	-	-	-	-	-	25.00
B-05	4	1	-	-	3	1	-	-	114.25
Basin Totals	12	2	2	0	7	1	0	1	336.25
MISSISSIPPI NORTH CENTRAL									
A-02	4	2	1	-	-	-	2	-	43.75
B-01	2	2	-	-	-	-	2	-	44.75
Basin Totals	6	4	1	0	0	0	4	0	88.50

Table 8. Continued.

Basin/ Segment	Iron (1.0 mg/l)	Copper (0.02 mg/l)	Manganese (1.0 mg/l)	pH (6.5-9.0)	Dissolved Oxygen (5.0 mg/l)	Sulfate (500 mg/l)	Lead (0.1 mg/l)	Mercury (0.5 mg/l)	Stream Mileage With Violations
MISSISSIPPI SOUTH									
A-02	4	-	2	1	1	4	-	-	44.75
B-01	1	-	-	-	1	-	-	-	8.75
Basin Totals	5	0	2	1	2	4	0	0	53.50
ROCK									
A-01	2	4	-	-	-	-	2	-	79.25
Basin Totals	2	4	0	0	0	0	2	0	79.25
SANGAMON									
A-04	1	-	-	-	-	-	-	-	13.75
A-06	Fluoride (1.4 mg/l) was the only mine related parameter in violation for this segment.								25.00
Basin Totals	1	0	0	0	0	0	0	0	38.75
GRAND TOTALS									
10 Basins/ 50 Segments	150	49	35	26	26	23	20	14	2686.5

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[1] IPCB general use standards are listed in column headings.

Water treatment costs are increased and, if sedimentation is severe, drainage channels may have to be cleared to prevent flooding.

Utilizing IEPA Water Quality Management Basin Plan data for 1975 (Table 8), Cooperative Wildlife Research Laboratory personnel determined stream mileage with mine related water quality violations. In each stream segment the furthest upstream sampling station with a mine related violation was located and downstream mileage to the first non-violating station or segment boundary was determined. When the locations of these upstream sampling stations were located downstream from surface and underground coal mine problem sites (Klimstra and Terpening 1974, Nawrot et al. 1977), the distance from the problem site to the first affected downstream sampling station was also included. This procedure identified mine related water quality violations in association with more than 2,600 miles of streams with the Illinois, Big Muddy and Kaskaskia River basins accounting for 63 percent of the total mileage recorded (Table 8). The presence of mine related violations associated with 2,600 miles of Illinois' waterways indicates the extensive off-site effects resulting from uncontrolled mine drainage. However, it should be pointed out that recording of a water quality violation for a mine related parameter does not imply either severe or chronic pollutional effects associated with the sampling station. Consequently, the total of 2,600 stream miles with "reported violations" should not be considered in the same light as the 400 miles which Schleuger (1975) identified as being "affected" by mine drainage.

Site-specific sampling and analysis of drainage from inactive coal refuse areas in Illinois has been conducted (Martin 1974, Nawrot et al. 1977). Martin (1974) reported refuse effluent analysis results (pH, total acidity,

sulfate, total iron, total solids, conductivity, ferrous iron) for eight disposal sites in Illinois. Streams receiving these effluents were converted from alkaline to acidic with a pH drop of 4 to 5 units; also, iron concentration increased from 1,000 to 2,000 mg/l.

Nawrot et al. (1977) collected and analyzed 500 samples from water on, or adjacent to, refuse areas at 245 inactive underground mine sites in Illinois. Three of the ten sample types included: above mine samples (60) collected upstream from the mine area to represent unaffected waters; general runoff samples (110), water originating from the mine site that flowed into adjacent waters; and, below mine samples (139) representing downstream waters influenced by mine drainage.

Above mine samples represented generally unpolluted waters; most samples were within IPCB general standards for water quality. Such samples were characterized by low total acidity, high pH values, and low metallic ion concentrations (Table 9).

General runoff samples associated with refuse areas had the lowest pH, and highest sulfate, acidity, conductivity, and soluble aluminum values of all sample types recorded. Median acidity was about 46 times that of above mine samples; the median pH 3.0 contributed to leaching of large concentrations of metallic ions into on site waters and adjacent streams. Large differences in median total acidity and pH of above mine and general runoff samples emphasized the toxicity of drainage from abandoned refuse areas.

Below mine samples demonstrated the adverse affects of uncontrolled mine refuse runoff on downstream water quality. Over half of all below mine samples were in violation of IPCB general standards (Table 7) for pH (52 percent) total iron (77 percent), sulfate concentration (63 percent),

Table 9. Chemical-statistical data for water samples collected from 245 abandoned underground mine sites in Illinois.[1]

Sample Type	pH	Total Fe mg/l	SO_4^{-2} mg/l	Soluble Mn mg/l	Total Acidity mg/l as $CaCO_3$	Conductivity micro-mhos/cm	Soluble Al mg/l
Above Mine (60)							
Median	7.4	0.90	330	0.0	9	800	0.2
Mean	6.9	19	820	8.0	50	1300	3.5
SD	1.47	82.7	2830	48.8	137	2770	13.5
Min	2.5	0.12	45	0.0	0	240	0.0
Max	8.4	620	22000	378	750	22000	92
General Runoff (110)							
Median	3.0	57	1300	6.4	415	2900	37
Mean	3.5	510	5200	21	3200	5100	240
SD	1.54	1260	10780	31.1	6450	6300	513
Min	1.6	0.36	31	0.0	4	180	0.1
Max	7.8	10000	89000	145	39300	32000	3100
Below Mine (139)							
Median	6.3		630	1.8	50	1350	0.8
Mean	5.4		1800	6.1	880	2100	75
SD	2.10		4850	10.2	3270	2400	285
Min	2.2		21	0.0	0	97	0.0
Max	8.5		41000	75	27800	17200	2500

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[1] From Nawrot et al. (1977).

and soluble manganese (60 percent). Seventy-nine percent of total acidity values exceeded the median above mine values; 88 percent of the conductivities and 73 percent of the soluble aluminum values also exceeded above mine values.

The analysis of refuse area run-off from inactive mine sites indicated acid mine drainage was adversely affecting Illinois waters and terrestrial areas. The reclamation of inactive ("pre-law") refuse areas is imperative as this uncontrolled source of pollution will continue to degrade the state's water quality despite current state and federal regulation of active refuse disposal areas.

Air Pollution

Air pollution resulting from the surface disposal of underground mining wastes is of two types: 1) emissions from burning refuse piles and 2) airborne particulates from barren or sparsely vegetated waste areas. Burning refuse piles represent a significant problem in some states (Stahl 1964), but few are present in Illinois. Stahl (1964) reported 14 burning piles while Nawrot et al. (1977) identified 6 at inactive sites in 1976.

Pollution from burning coal waste is usually localized and often affects only small rural communities (Hall 1962). In Illinois, McNay (1971) found all such fires more than 1 mile from a town; Nawrot et al. (1977) reported burning was not extensive on sites they evaluated. However, burning gob can release significant amounts of CO, SO_2, H_2S, nitrogen oxides, hydrocarbons, and particulates (Sussman and Mueller 1964, Hoffman 1970). These emmissions can impair the health of nearby residents, restrict visibility, harm vegetation, corrode materials, and reduce aesthetic values (Sussman and Mueller 1964, McNay 1971). Although these environmental and health problems indicate

the potential severity of air pollution from burning refuse piles, they are not a major concern at active mines. Techniques have long been available (though not always utilized) for preventing refuse pile fires (Hebley 1948, Corey et al. 1956). In fact, current reclamation laws incorporate requirements for layering, compacting, and covering refuse to prevent spontaneous combustion (Illinois Pollution Control Board 1972, P.L. 95-87).

A more common, and thus more important, source of refuse-related air pollution is airborne particulates. Refuse sites are initially devoid of vegetation due to disposal activities and the toxicity of the refuse; the sites remain barren as long as the toxic substances are present. Without vegetative cover, soil and refuse particles are easily moved by the wind. If large expanses of dry, fine refuse are present, blowing particulates can be a problem. Windblown dust can prevent exchange of gases by plants, interfere with pollination, increase susceptibility to disease, and bruise tissue (Anon. 1969). However, wind-carried particulate pollution is usually localized and of little concern outside the immediate area.

Legislation Affecting Current Refuse Disposal Practices

As a result of growning public awareness and concern over the environmental impacts of coal mining (both surface and underground), and refuse disposal, legislation to mitigate environmental and safety problems associated with surface coal mining and refuse disposal in Illinois was established, beginning in 1962 with passage of The Open Cut Land Reclamation Act (H.B. 306). More restrictive standards for surface mining and refuse disposal were implemented in 1971 and 1975 with enactment of The Surface-Mined Land Conservation and Reclamation Act (P.A. 77-1568 and H.B. 1277).

Specific regulations to alleviate underground mine related pollution were first delineated in the Illinois Pollution Control Board (IPCB) Regulations, Chapter 4, 1972. These regulations stipulated that refuse piles and slurry ponds be graded and vegetated in accordance with the grading and revegetation standards of Sections 6206 (a), (f), and (k) of the Illinois Surface-Mined Land Conservation and Reclamation Act of 1971 (Illinois Pollution Control Board 1972). Recently enacted federal legislation (P.L. 95-87) in addition to current state regulations, should alleviate further environmental impacts resulting from surface disposal of refuse.

Federal regulations require refuse embankments be constructed with adequate safety and environmental controls; disposal areas must be stabilized and surface water runoff controlled during active mining and refuse disposal. Refuse sites must be graded and covered with 4 feet of the best available non-toxic and non-combustible material; and, permanent vegetation must be established in accordance with the designated post mining use.

These laws eliminate problems of water and air pollution, and aesthetic disamenity associated with refuse disposal. These measures will minimize or eliminate the on- and off-site affects associated with weathering, leaching, and erosion of untreated acid producing refuse materials. However, costs involved with disposal, land aquisition, decreased value of lands affected by refuse disposal, and reclamation of disposal sites, may force reevaluation of past and present disposal methods and subsequently result in consideration of alternative disposal techniques.

Current Refuse Disposal Practices

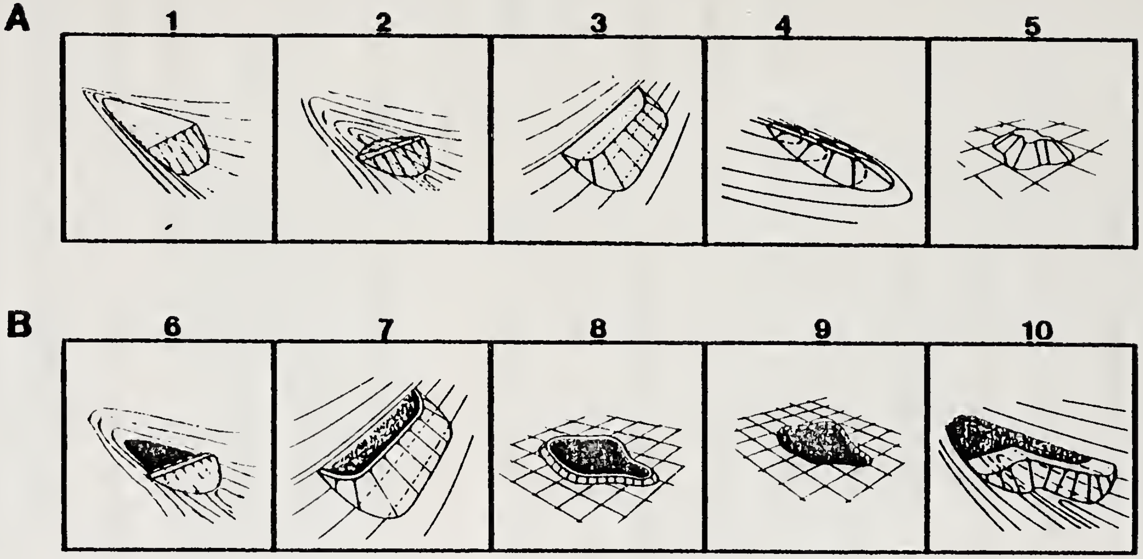
In response to legislation providing stricter environmental and engineering standards for refuse disposal, the coal industry has altered

disposal methods. Greater technical and engineering expertise is employed in disposal structures, and refuse is covered by 4 feet of soil material and subsequently vegetated to contain potentially environmentally harmful material.

As previously discussed, coal refuse from preparation plants occurs as coarse and fine materials. The former is transported by truck, conveyor belt, or aerial tram to a disposal site. If an underground and surface mine share a common preparation plant, the refuse may be deposited in a permitted, final cut or incline; otherwise surface disposal is common practice for underground mines. Deep mine disposal areas resemble one, or a combination of, five basic forms (Figure 9). The pile type disposal predominates in the level topography of the Midwest, including Illinois; other techniques are found in rolling and mountainous terrain of Appalachia.

Pile type disposal areas are formed by continuous dumping, spreading and compacting of coarse refuse materials to form a flat-topped mound while compacting and sloping the sides to prevent erosion and slides. If steeper slopes are desired, terracing is required; compaction is necessary to hold the material in place and retard air and water pollution. When refuse deposition is terminated, soil cover is applied and vegetation established. The oxidation of gob and subsequent production of acid water is reduced by this compaction and covering; air pollution is also eliminated.

Fine refuse is transported by pipeline from the preparation plant to a settling or dewatering pond. Preparation plants of surface mines may pump slurry onto and between graded and ungraded spoilbank areas; other slurry impoundments resemble one of five basic types (Figure 9); diked and incised ponds are the common types in Illinois. The embankments may be constructed of clay; but, they are often of coarse refuse, with perhaps



(A) Type of dump:
- (1) Valley-fill
- (2) Cross-valley
- (3) Side-hill
- (4) Ridge
- (5) Pile

(B) Type of impoundment:
- (6) Cross-valley
- (7) Side-hill
- (8) Diked
- (9) Incised
- (10) Complex: Cross valley-side-hill

Figure 9 Types of coal refuse disposal structures (Schlick and Wahler 1976).

some rock or clay materials incorporated to add support and/or impermeability to the dike. Design and construction of coal refuse dams differ from traditional earthen dams in that the embankment serves as an active coarse refuse disposal area while concurrently serving as a dike for the slurry impoundment.

Three general approaches are used in constructing refuse embankments, based on the method of deposition of the constituent materials; an upstream method deposits the coarse refuse into the pond from the starting point of the dike (Figure 10); a downstream method, deposits each layer away from the pond (Figure 11); and a centerline method with equal deposits of materials on either side of the center of the dike (Figure 12). The deposited materials may also be homogeneous (Figure 13), with a standard mix of particle sizes throughout the dike; or zoned with layers of materials of different sized particles (Figure 14). A central core of impermeable (e.g. clay) material may be added to control seepage in coarse refuse embankments.

As environmental regulations prohibit the discharge of polluted water from a mine site (Illinois Pollution Control Board, 1972, Chapter 4 and P.L. 95-87), water from slurry ponds is commonly being reused in the coal preparation plant once the fine refuse particles have settled. Slurry is discharged into one end of the impoundment, the solids settle out, and clarified water is then decanted from the opposite end. The decant then may be passed through more than one pond to permit additional settling of particulate matter and reused, allowed to evaporate, or treated and discharged. Once the impoundment is filled with slurry, it also must be covered with 4 feet of soil cover and vegetated. In many operations gob is spread and compacted over the slurry and finally covered with soil.

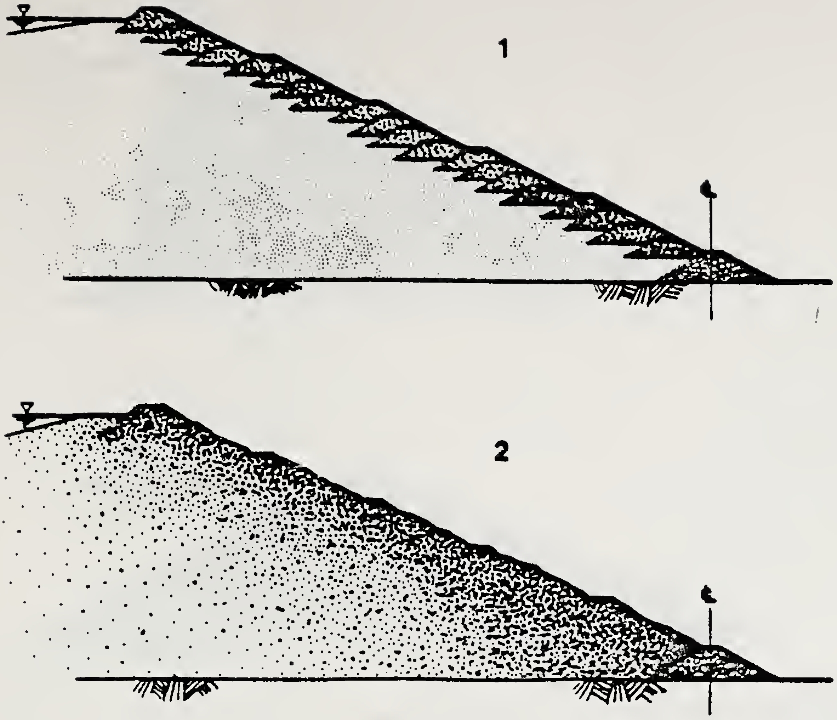


Figure 10. Upstream construction method for a refuse embankment; (1) mechanically constructed dike, (2) hydraulically constructed dike (Schlick and Wahler 1976).

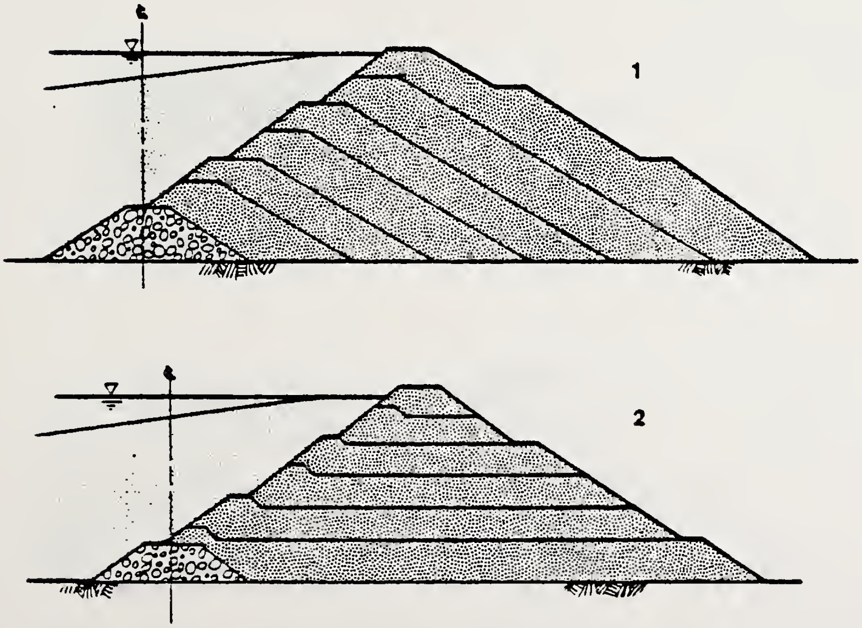


Figure 11. Downstream construction method for a refuse embankment; (1) inclined method, (2) horizontal method (Schlick and Wahler 1976).

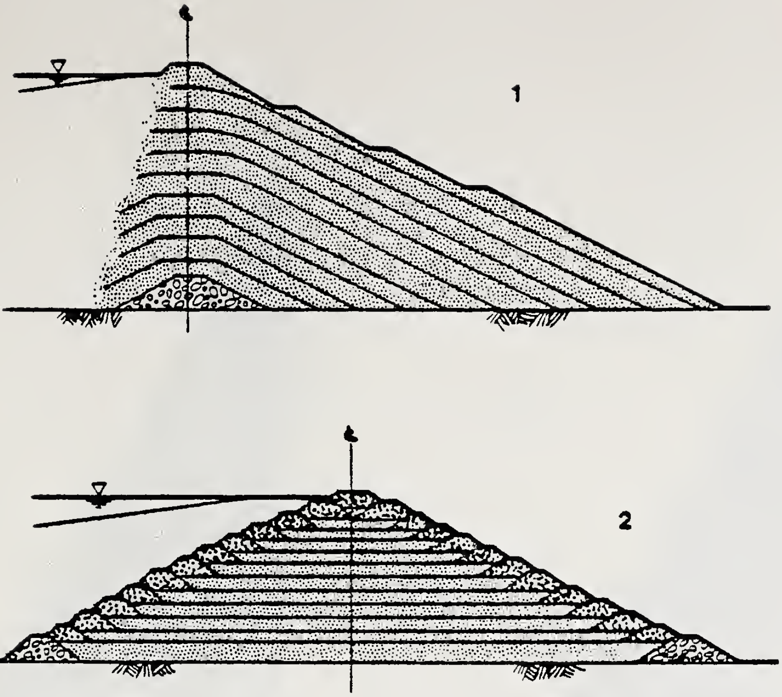


Figure 12. Centerline construction method for a refuse embankment; (1) buttress or leaning embankment, (2) freestanding embankment (Schlick and Wahler 1976).

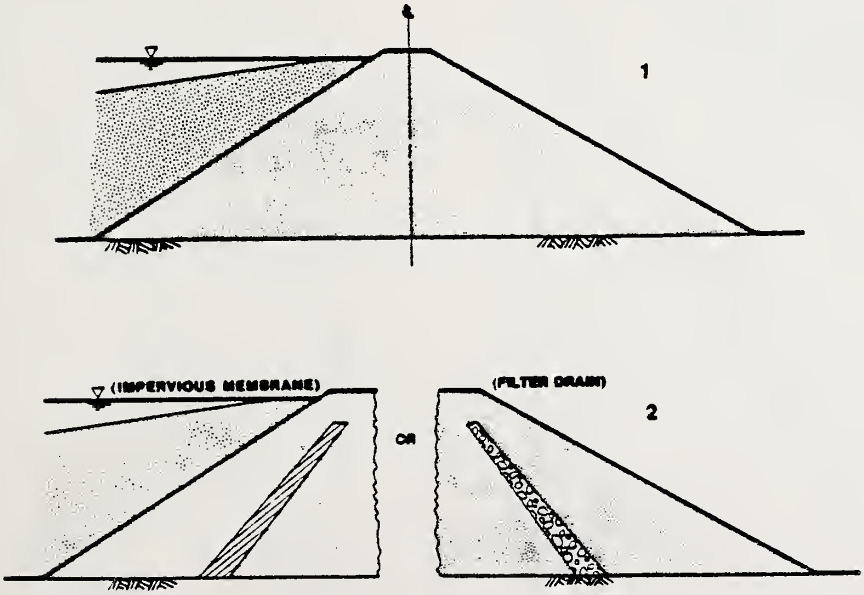


Figure 13. Homogeneous construction method for a refuse embankment; (1) homogeneous, (2) modified homogeneous (Schlick and Wahler 1976).

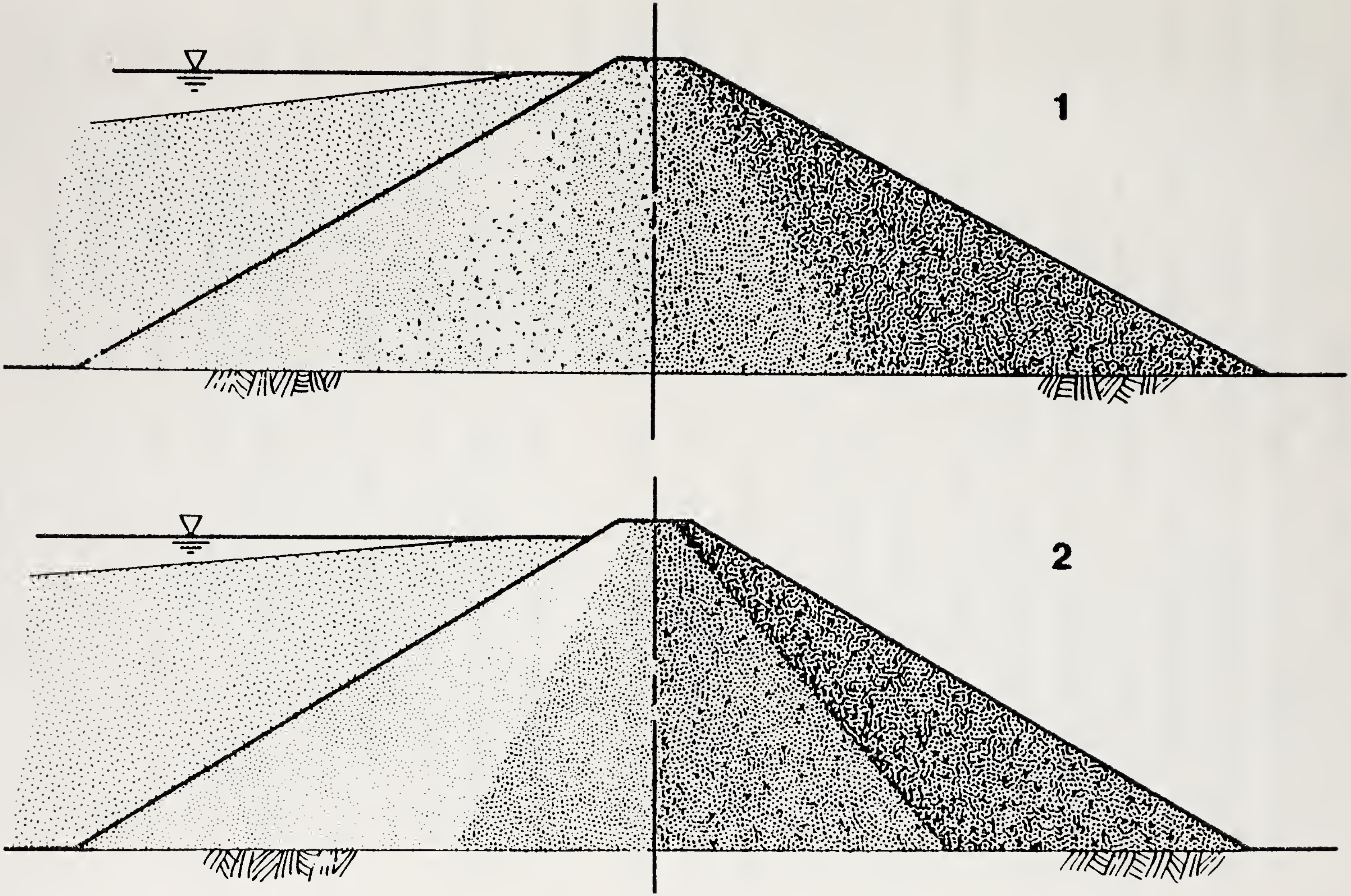


Figure 14. Zoned construction method for a refuse embankment; (1) transitional zones, (2) definitive zones (Schlick and Wahler 1976).

Refuse Disposal Practices in Illinois

Methods of refuse disposal and acreage directly affected by disposal sites from Illinois underground coal mines were determined through: (1) interpretation of current (1978) aerial photographs of active underground mines in Illinois provided by the Illinois Department of Mines and Minerals Division of Land Reclamation (IDMM-DLR); (2) discussion with IDMM-DLR personnel, industry representatives and respective mine engineers for each mine; and (3) utilization of permit information from IDMM-DLR. Acreages associated with refuse disposal appear in Table 10 and Figure 15.

The extent to which raw coal is prepared determines the acreage required for refuse disposal. Six of the active underground coal mines do not wash coal and remove only the initial coarse refuse (breaker rock). Consequently, refuse generated is considerably less than for mines with more extensive processing. An average of only 9 acres per mine is used for disposal of breaker rock compared to 143 acres per mine where coal is washed (Figure 16, Table 10).

Four underground mines dispose of refuse on adjacent property that was previously surface-mined. Coarse refuse as well as slurry may be deposited in final cuts or inclines (Figure 17); in some cases slurry may be deposited on previously surface-mined land (Figure 18). Two mines dispose of coarse refuse in borrow pits which are excavated, filled with refuse, and covered with soil removed from the next cut (Figure 19).

Most underground mines dispose of refuse on the surface of undisturbed land. Coarse materials are placed in a pile (Figure 20) and continuously spread and compacted to form flat-topped, often terraced, mounds. Upon completion of disposal activities, the site is covered with topsoil (Figure 21) and vegetated (Figure 22). In some cases sides of the pile are covered

Table 10. Coal refuse disposal acreage at active underground mines in Illinois counties as of May 1978 and potential refuse acreage increases.[1]

County	Number of Mines	Refuse Acreage as of 1978					Total 1978 Refuse Acreage	Potential Acreage Increase by 1995	Total Acreage Potentially Present by 1995
		Gob	Slurry	Unwashed Refuse	Runoff Retention	Clay Dikes and Topsoil Areas			
Christian	1	130	105	0	25	44	304	150	464
Clinton	1	1	10	0	0	37	48	167	215
Douglas	2	19	15	17	0	0	51	29	80
Franklin	4	107	325	4	0	38	474	*	474
Gallatin	1	51	30	0	21	20	122	21	143
Jefferson	3	190	221	0	0	29	440	100*	540
Macoupin	2	141	127	0	0	99	367	343	710
Montgomery	1	0	0	7	0	4	11	5	16
Randolph	3	83	71	16	0	31	201	104	305
St. Clair**	1	104	176	0	0	14	294	*	294
Saline**	2	62	105	0	0	0	167	*	167
Wabash	1	0	0	9	0	3	12	31	43
Williamson	3	106	176	0	0	0	282	121	403
State Totals	25	994	1,361	53	46	319	2,773	1,071	3,844

Table 10. Continued.

[1] Source: aerial photographs of refuse sites and estimates from mine engineers.

*Undetermined additional acreage may be required.

**Accurate refuse acreage measurement is impractical because underground mine and surface mine refuse are deposited together between spoilbanks of an inactive surface mine. Estimates were made based on the total refuse acreage and the proportion of coal produced by the underground mine. Saline County acreage was estimated from St. Clair County figures (8.1 acres of gob/million tons of coal; 13.6 acres of slurry/million tons of coal).

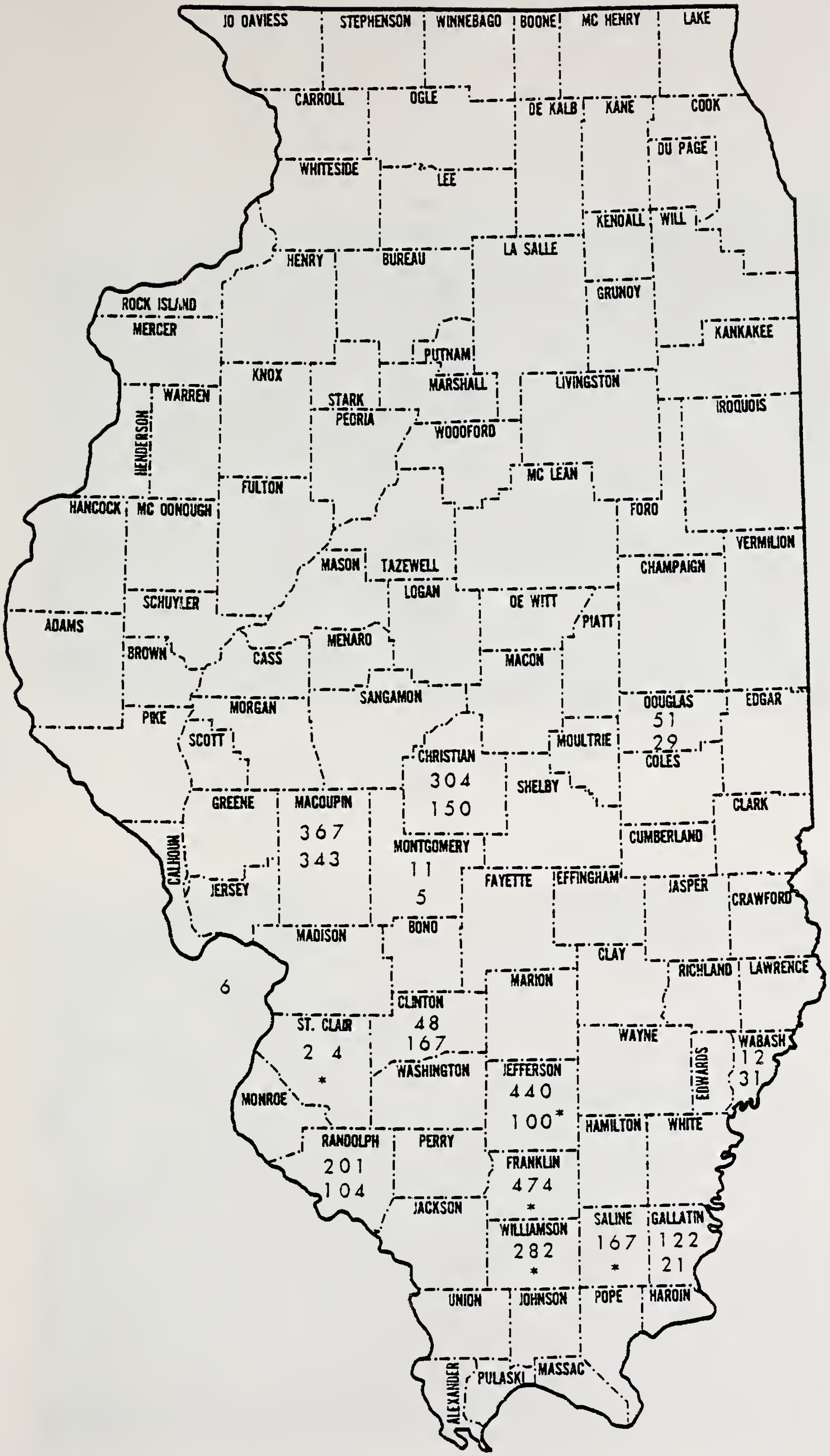


Figure 15. Acreage of coal refuse at active underground coal mines in Illinois counties as of 1978(upper number) and planned expansion acreage(lower number) (*indicates undetermined additional acreage will be required)(see text for source).

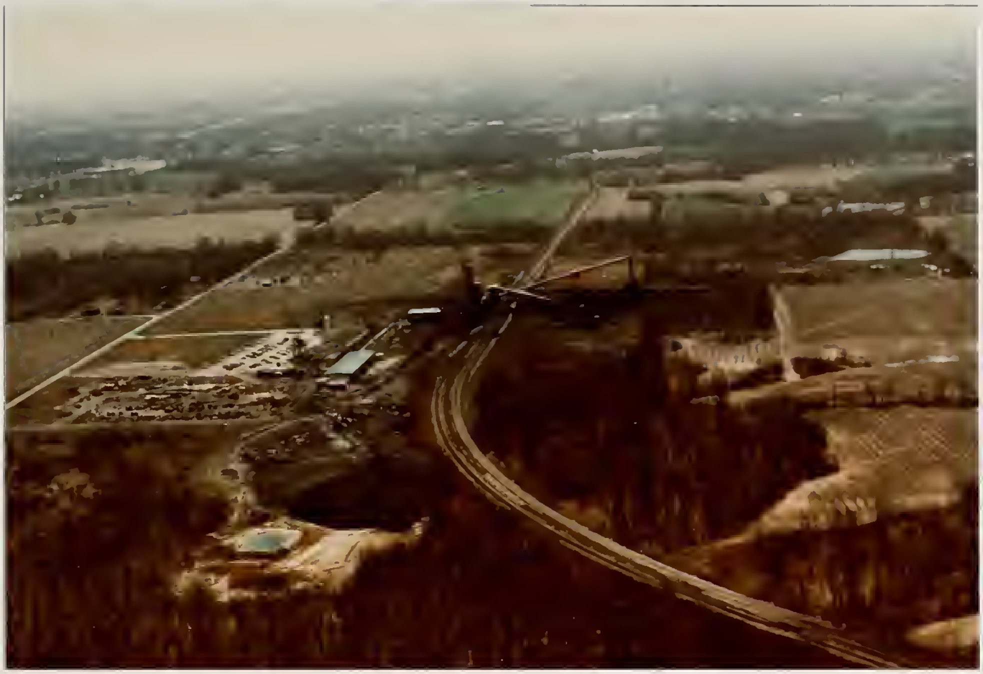


Figure 16. Refuse site associated with an underground mine that only disposes of breaker rock.

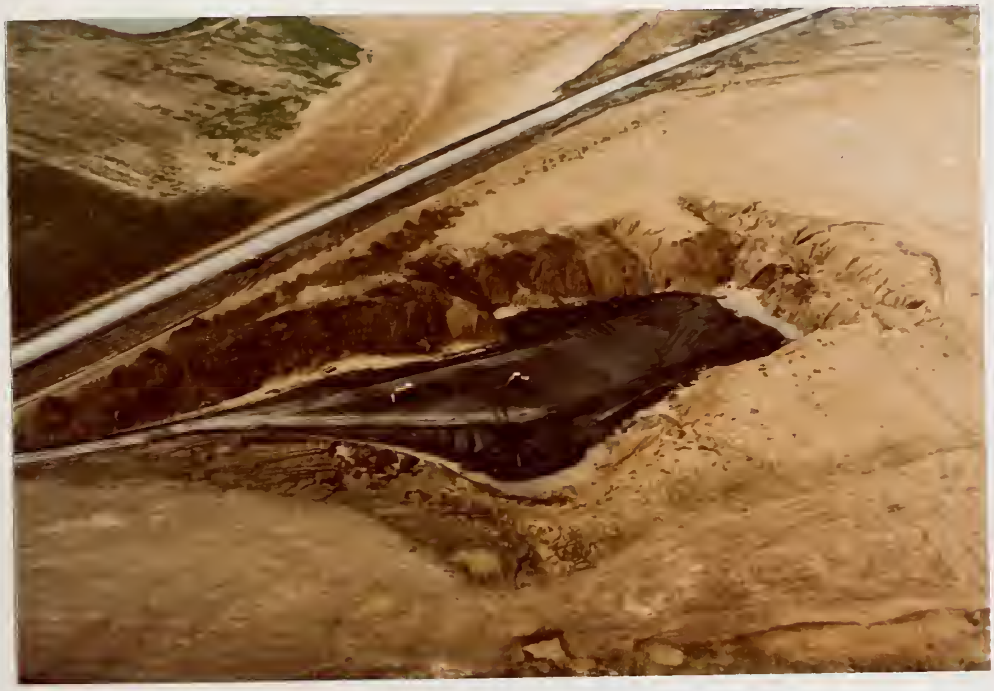


Figure 17. Coarse refuse disposal associated with a surface mine operation.

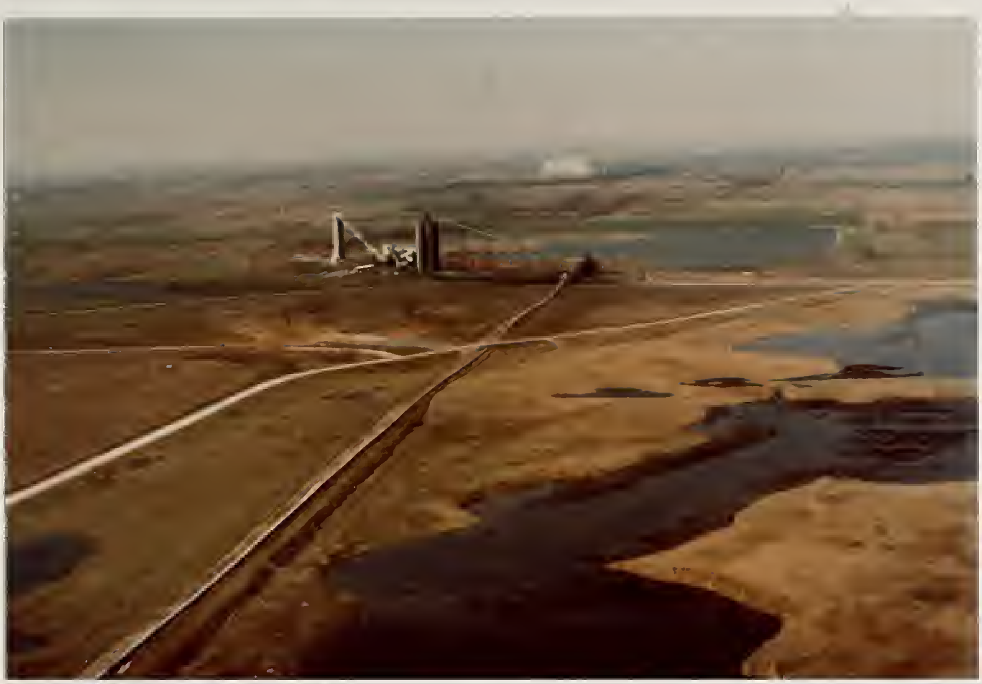


Figure 18. Slurry disposal on previously surface mined land.

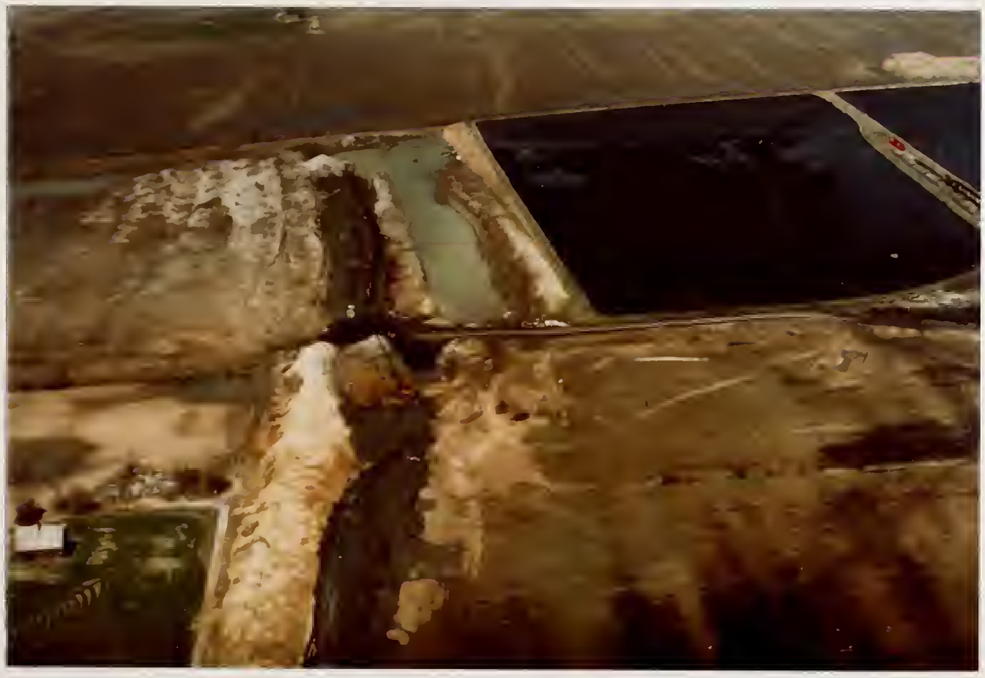


Figure 19. Coarse refuse disposal in pits dug for that purpose.

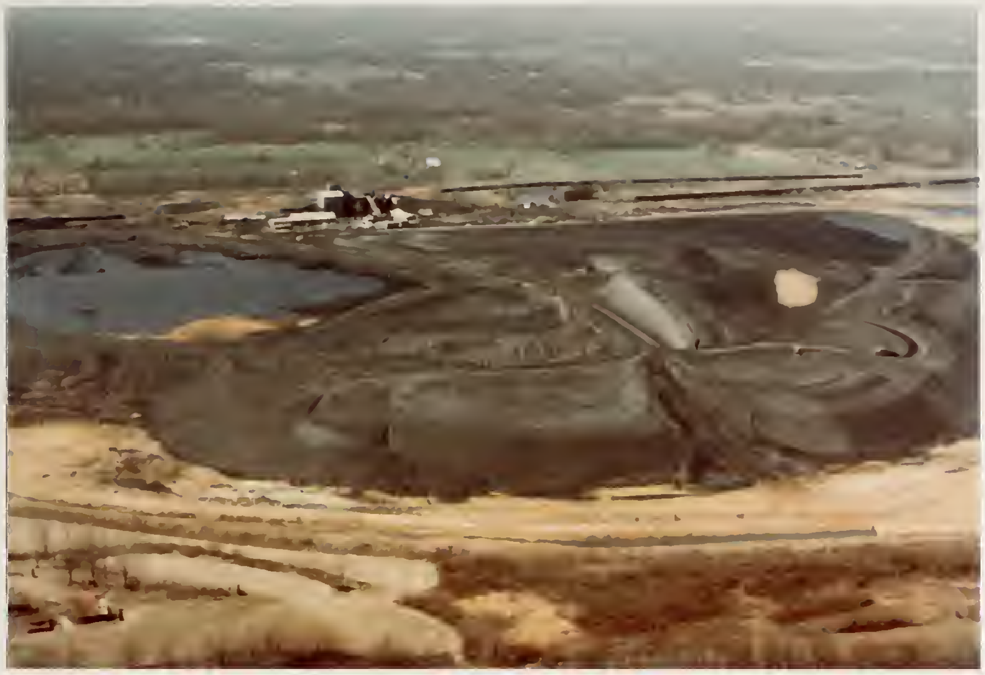


Figure 20. Pile type coarse refuse disposal structure.

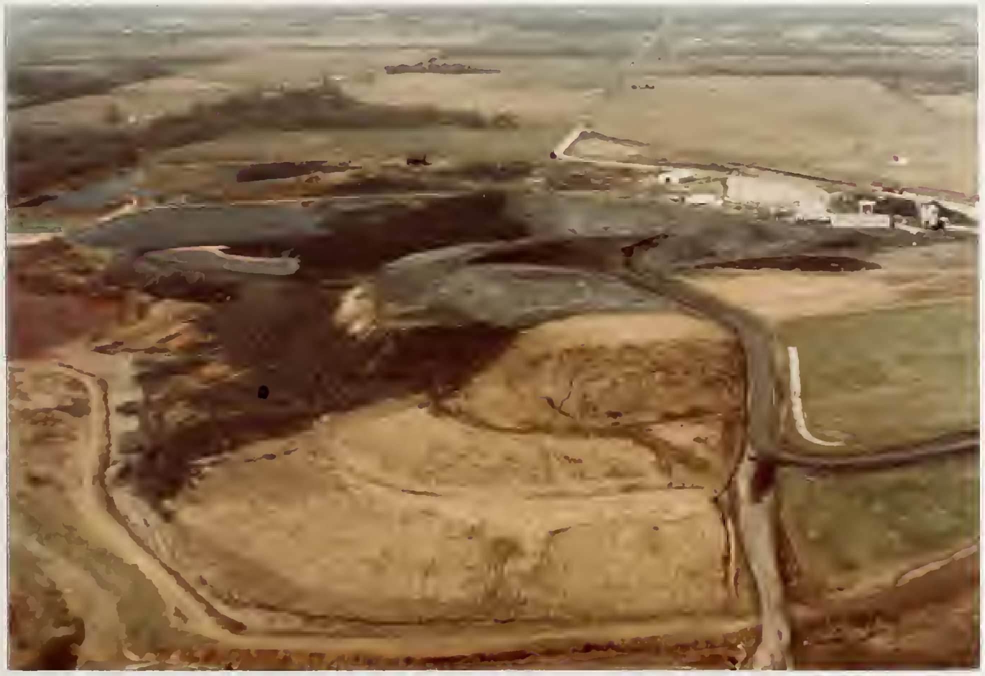


Figure 21. Partial soil coverage and vegetation establishment on a previously graded and terraced refuse disposal pile.

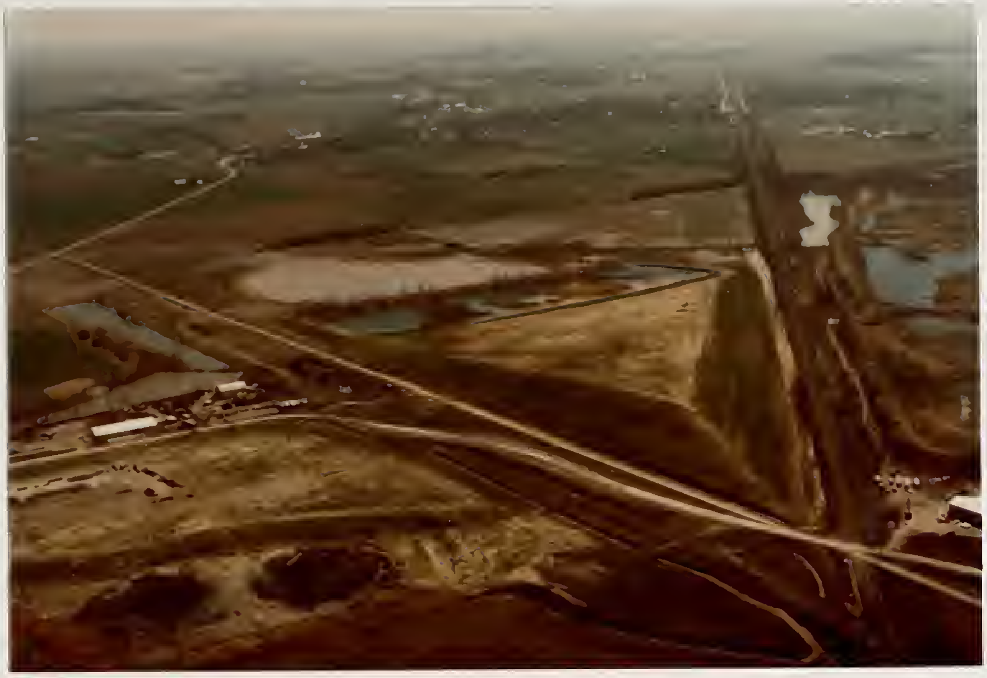


Figure 22. A graded and covered refuse disposal pile.

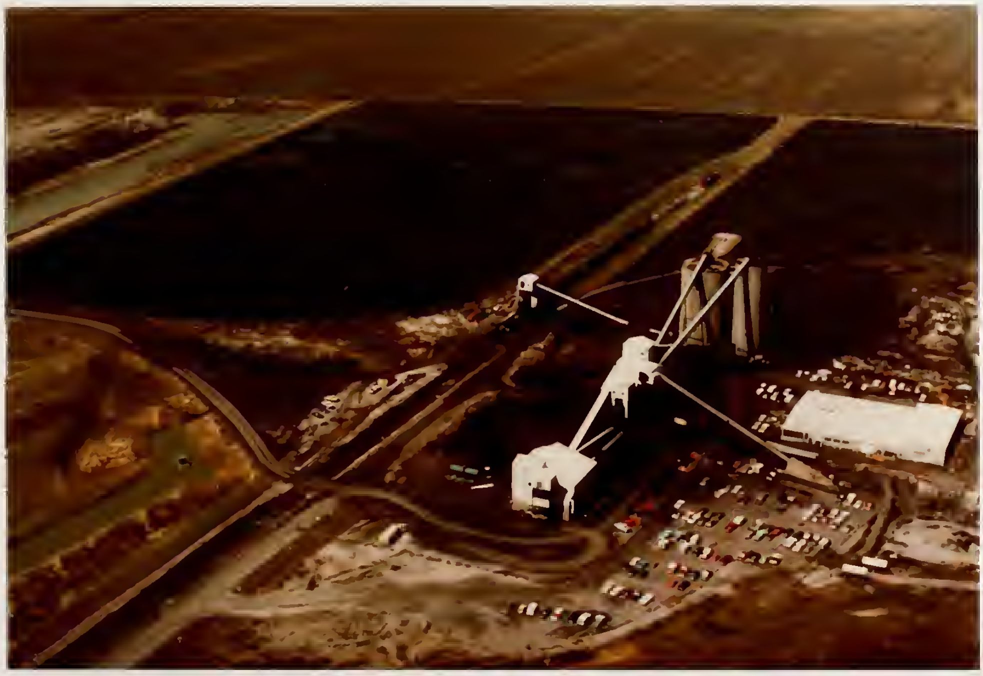


Figure 23. Incised type slurry disposal impoundment.

with soil and vegetated concurrent with refuse deposition; consequently, only the top of the pile needs to be covered with soil and vegetated when disposal activities are completed. The slurry ponds of these mines are of the incised type (Figure 23) or the diked impoundment-type (Figure 24). The embankments are usually constructed of coarse refuse material; the slurry pond is often contained within the coarse refuse pile (Figure 24). Filled slurry ponds, once dewatered, may be covered with coarse refuse (Figure 25), which is subsequently covered with soil and vegetated.

Costs associated with disposal of refuse include 1) purchase of land and initial site preparation, 2) coarse refuse handling, 3) fine refuse handling, and 4) insurance, engineering tests, and emergency repairs (Brown et al. 1977). Expense for each of these phases differs between mines and between disposal techniques. A 1975 study determined 34 cents/ton of coal to be the average cost of surface disposal (National Academy of Science 1975). A more recent investigation (Brown et al. 1977) indicated 66 cents to be the average disposal cost per ton of coal. Both studies assumed refuse would be disposed of in a valley behind a single embankment. The average cost per ton for Illinois mines would be higher as the refuse would be disposed of on flat ground requiring embankments on all sides (U.S. Bureau of Mines 1973, Jankousky 1977); this type impoundment involves more labor and soil.

Based on the conservative estimate of 66 cents per ton of coal, the cost associated with surface disposal of underground coal mine refuse in Illinois in 1977 was $19,529,000. If production increases as expected (Table 1), the annual cost by 1995 would be $38,201,000 provided factors of cost remained constant, an unlikely assumption.*

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*By 1978, with 7.4 percent rate of inflation, the cost of disposal would increase to 70.9 cents per ton of coal produced.

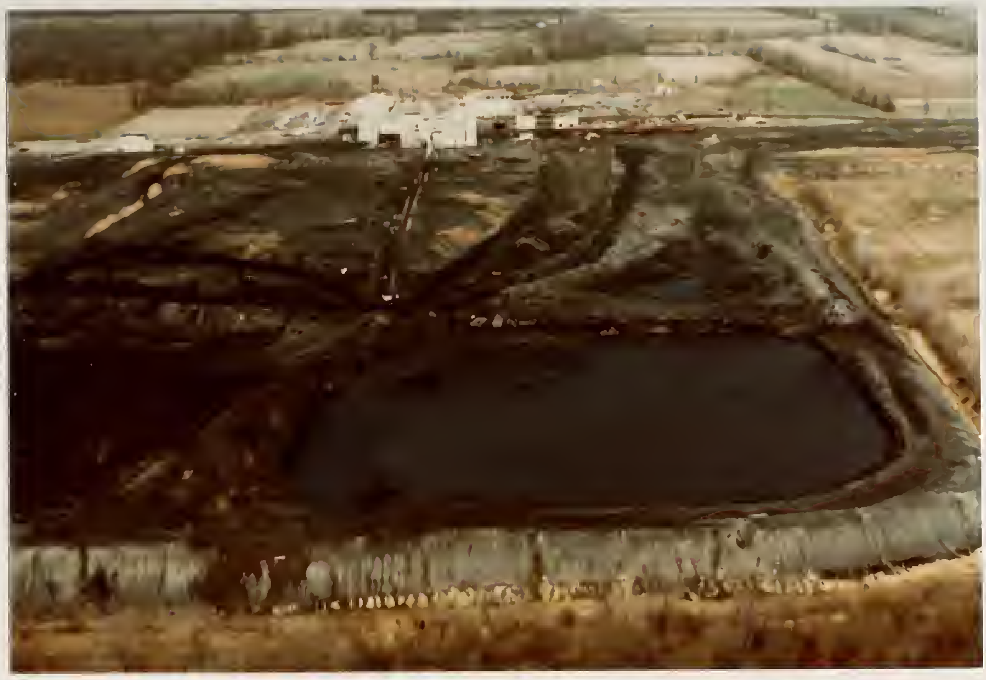

Figure 24. Diked type slurry disposal impoundment.

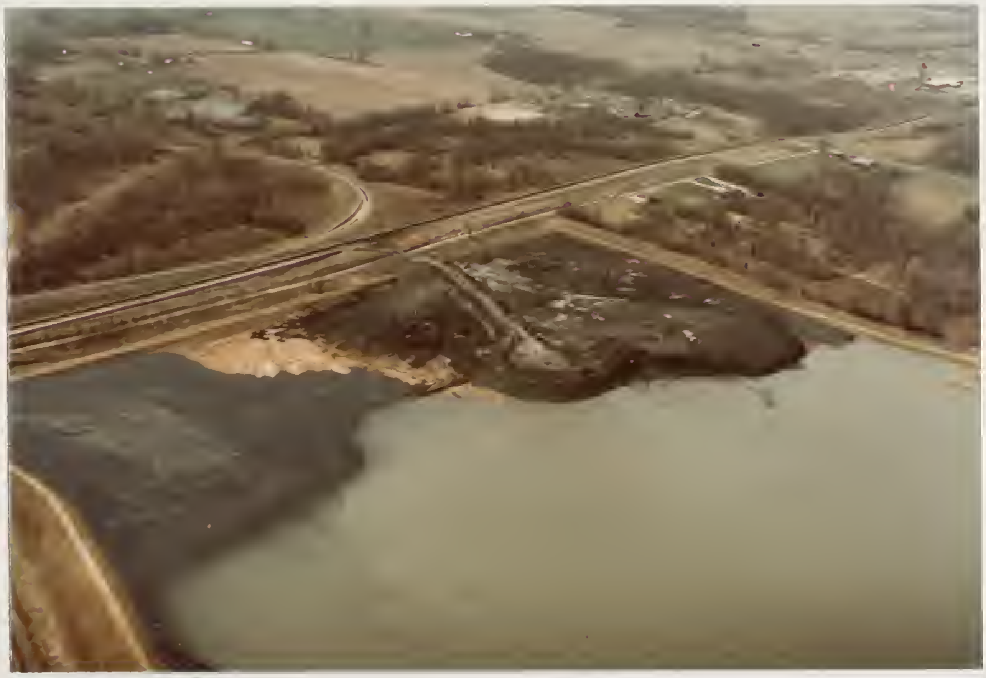

Figure 25. Final deposition of coarse refuse in a filled slurry disposal impoundment.

Included in such costs are expenses of abating water and air pollution; in addition to basic disposal costs increased control of fugitive dust may raise the cost of refuse disposal by 1 cent per ton of coal, $296,000 at present production rates.

Although environmental problems associated with refuse disposal have been addressed and rectified by current regulations, altered land use at the disposal site, with associated loss of productivity, property values and tax revenues are not.

The costs associated with pollutants resulting from mine refuse disposal sites are no longer being indirectly absorbed by the public as a consequence of off site environmental pollution and necessary "after the fact" treatment programs. As pollutants are currently contained on the refuse site, pollution abatement is born by the mine operator through treatment and reclamation measures; however, these treatment costs are, of course, passed on to the energy consumer. The cost associated with environmentally and legally acceptable disposal techniques is the best indication of the cost of actual or potential environmental pollution associated with refuse disposal.

Impact of Current Refuse Disposal in Illinois

Land-use Changes

Surface disposal of underground-mined coal refuse will affect an area by restricting possible future uses of land. The full impact of this factor will only be realized when need for cropland or residential property may accentuate such losses due to refuse disposal. Most sites in Illinois occupy land surface that was previously used for agriculture. The Surface Mining Control and Reclamation Act of 1977 requires that such

areas be restored to their pre-mined capabilities; however, common post-mining land use on Illinois refuse sites will probably be as pasture or wildlife habitat and not as cropland. In addition, the 4 feet of material needed to cover refuse areas will need to be obtained, in the case of existing disposal sites, from adjacent borrow areas, further contributing to the total disturbed acreage.

The amount of land for surface disposal of underground mine refuse is small relative to the acreage lost to transportation and building developments. Data from four typical active mines with completed refuse impoundments indicate an average of 5.9 acres to dispose of refuse from each million tons of coal produced. Using this figure and the estimated annual coal production of 58 million tons, the additional land necessary for refuse disposal would be 343 acres per year by 1995. In contrast, between 1954 and 1969 expansion of urban areas, highways, airports, and railroads required approximately 46,000 acres in Illinois annually (Wooten and Anderson 1957, Frey 1971).

Obviously, refuse sites will not be the primary cause of loss of agricultural land as long as other non-coal related development continues. More importantly, unlike other developments, refuse sites are not permanently removed from agricultural use, as theoretically they can be returned to limited production for forage or other productive uses. However, intensive utilization of soil covered refuse areas must be approached with caution, as such areas are fragile environments, which if mismanaged could be easily eroded. Minor disturbance of the soil mantle can expose potentially toxic mine refuse to oxidation resulting in a local problem capable of rapidly spreading and destroying a very expensive reclamation effort.

Tax assessment and revenue

Illinois land is assessed for property taxes according to the recent selling price of nearby land and the income produced by the property (Illinois Department of Local Government Affairs 1975). This means that in most counties rural land assessment is a function of market values and land use (e.g. cropland, forest, or pasture). Similarly, urban property is assessed according to market value and to whether it has a commercial, industrial, or residential designation.

Transfer of real estate from an individual owner to a coal company may result in a change of assessment when the mine opens; however, all refuse site assessments do not change in the same direction. Depending upon the judgement and policy of the county supervisor of assessments and the local township assessor, a mine refuse disposal site may be assessed as wasteland, as industrial property, or the same as adjacent property; consequently, the tax revenue produced by the land varies accordingly. Information from county assessment offices indicates that of the 13 Illinois counties with active underground coal mines, 7 assess refuse sites at the same value as adjacent land, 4 assess refuse lands at a value lower than the pre-refuse value, and 2 view refuse sites as industrial property and assess it at a high value.

While a mine is active, taxes on equipment, structures, and property around the mine opening are greater than tax losses incurred due to devaluation of refuse-covered land (Jefferson County Assessment Office, personal communication). However, the tax revenues disappear when the mine closes and valuable equipment and structures are removed. The refuse-covered property may also be reassessed to a lower value, if it was not already assessed as wasteland. Therefore, county tax revenue

from an underground mine, although substantial during the life of the mine (approximately 25 years), may be kept low permanently after the mine closes because of the presence of the refuse disposal site. To estimate the effect of refuse disposal on the tax base in Illinois counties, comparisons have been made between the assessed values of refuse and non-refuse sites (Table 11 and Table 12).

To determine the effect that the presence of a refuse disposal site has on the assessed value of land, real estate assessment rates were obtained from the Supervisor of Assessments in each Illinois county containing an active or abandoned underground-mined coal refuse site. Assessment supervisors provided an average tax assessment rate per acre for urban, rural, residential, oldfield, forest, agricultural, and refuse disposal in their counties. When average rates could not be provided, rates for sample tracts containing these land use types were requested. According to most Assessment Supervisors, tax assessment figures for rural lands were accurate; but, the rates for urban lands were general as urban property values changed greatly with location. Location and acreage of refuse disposal sites were obtained from mined land inventory files of the Cooperative Wildlife Research Laboratory.

The potential assessment difference in each county was determined by multiplying the refuse-covered acreage by the assessed value per acre and subtracting this value from the assessed value of an equal acreage of adjacent property. Land use on adjacent property was assumed to be the same as that on the refuse-covered land prior to waste disposal; and, the difference in assessments was expected to reflect the loss of potential tax revenue due to the disposal of mine refuse. It should be noted that assessed value is not the amount paid as tax; the tax due is a percentage

Table 11. Difference in assessed value between abandoned refuse sites and adjacent property and the potential tax revenue lost to Illinois counties.

County	Refuse Acreage[1]	Difference Between Assessed Value of Refuse Sites and Adjacent Property[2]	Potential Annual County Tax Revenue Lost[3]
Bond	0.4	$ 64	$ 3
Bureau	142.7	91,864	4,740
Clinton	5.3	933	45
Edgar	3.8	985	36
Franklin	630.6	185,630	13,479
Grundy	159.3	65,482	2,442
Jackson	118.0	13,841	860
Knox	9.6	734	37
LaSalle	131.4	97,753	4,594
Livingston	15.2	8,035	366
Logan	4.2	966	46
Macoupin	202.9	199,891	9,235
Madison	174.9	48,229	2,701
Marshall	49.3	36,406	1,565
McLean	3.5	7,970	407
Menard	5.3	2,137	100
Mercer	21.3	3,604	169
Montgomery	71.2	11,136	498
Perry	231.2	31,638	1,430
Putnam	56.6	41,101	1,385
Randolph	188.7	21,819	796

Table 11. Continued.

County	Refuse Acreage[1]	Difference Between Assessed Value of Refuse Sites and Adjacent Property[2]	Potential Annual County Tax Revenue Lost[3]
St. Clair	268.7	41,390	2,521
Saline	216.9	43,656	2,331
Sangamon	37.2	54,965	2,979
Vermilion	163.2	34,617	1,980
Will	65.4	7,555	476
Williamson	519.9	52,165	2,687
Woodford	14.8	19,424	917
Totals	3,511.5	$1,123,990	$58,825

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[1] Source: Nawrot et al. (1977)

[2] Source: estimated from information given by county assessment officials (see text)

[3] Calculated with 1975 tax rates (Illinois Department of Local Government Affairs 1978)

Table 12. Estimated assessed value of underground-mined coal refuse sites and adjacent property and estimated annual loss of potential tax revenue in Illinois counties which assess refuse sites at lesser values than adjacent property.[1]

County	Refuse Acreage	Assessed Value of Refuse Acreage	Assessed Value of Adjacent Property	Difference	Potential Tax Revenue Lost
Franklin	474	$ 45,826	$ 54,510	$ 8,684	$ 631
St. Clair	250	$ 13,757	$ 45,000	$ 31,243	$ 1,903
Wabash	43	$ 2,580	$ 17,243	$ 14,663	$ 663
Williamson	282	$ 9,400	$ 45,402	$ 36,002	$ 1,854
Totals	1049	$ 71,563	$162,155	$ 90,592	$ 5,051

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[1] Assessed property values estimated from information provided by county supervisors of assessments. Source for tax rates: Illinois Department of Local Government Affairs (1978).

of the assessed value and is based upon the taxing rate which is dictated by the projected annual budget for each county (Illinois Department Local Government Affairs 1975).

Only four counties currently assess active coal refuse disposal sites at values lower than surrounding property. The potential tax revenue estimated to be lost annually to these counties is $5,051 (Table 12); but, this represents only 0.1 percent of the total annual real estate taxes collected in the four counties. As mentioned above, devaluation of refuse property may not occur until after the mine closes.

The assessed value of inactive coal refuse sites in Illinois indicates the effect of tax losses following a mine closing. The difference in estimated assessed values between inactive refuse sites and adjacent property is approximately $1,123,090 (Table 11), representing an annual loss of $58,825 in potential tax revenue. Estimated annual tax losses in individual counties ranged from $3 to $13,479. Even the largest of these tax losses is small relative to the total county budget; nevertheless, the sums may represent significant losses to local townships or fire protection and school districts.

Currently active refuse disposal sites will probably be reclaimed to wildlife habitat or pasture. Relative to current cropland tax revenues, reclamation to wildlife habitat, if assessed as such, would result in a loss of potential tax revenue of approximately $26,504 annually (Table 13). If these lands were reclaimed to and assessed as pasture, the loss of potential tax revenue would be over $17,669 annually (Table 13). Again, these small sums would be important only to local tax districts. Besides tax revenue, additional income can be lost when agricultural land is permanently removed from row-crop production. This lost agricultural productivity is financially compensated for during the life of the mine

Table 13. Potential tax revenue lost if refuse from currently active mines is reclaimed and assessed as wildlife habitat or as pasture.

Assessed value of 3,844 acres of cropland (average $235/acre)[1] = $903,340

Assessed value of 3,844 acres of wildlife habitat (average $94/acre) = $361,336

difference = $542,004

average annual tax rate = .0489

potential annual tax revenue lost = $ 26,504

Assessed value of 3,844 acres of cropland (average $235/acre) = $903,340

Assessed value of 3,844 acres of pasture (average $141/acre) = $542,004

difference = $361,336

average annual tax rate = .0489

potential annual tax revenue lost = $ 17,669

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[1] Assessed value is assigned by county tax assessors and represents approximately 33 percent market value of the land. The given assessed values per acre of cropland, wildlife habitat and pasture were averaged from 1978 estimates provided by county supervisors of assessment for each Illinois county containing past or present underground coal mining. The estimated assessed values for cropland ranged from a low of $75 per acre in Jackson County to a high of only $453 per acre in Sangamon County.

by industrial productivity; afterwards however, revenue from row-crops formerly produced on disposal sites is permanently lost. A cost estimate of lost row-crop capability associated with the 3,844 acres of current and future (through 1995) refuse disposal areas can be obtained by calculating the annual revenue for average yields (Fehrenbacher et al. 1978) of corn, wheat or soybeans. Based on average 1978 harvest prices (Personal communication, Dr. W. M. Herr, Department of Agribusiness Economics, Southern Illinois University at Carbondale), $831,457 would be lost annually if corn (103 bushels/acre @ $2.10/bushel) was produced; $796,631 if soybeans (33 bushels/acre @ $6.28/bushel) were produced; and $368,563 if wheat (34 bushels/acre @ $2.82/bushel) was produced. As these figures represent only an annual loss a much greater economic impact is realized when this annual loss is projected for the entire length of time (perhaps indefinitely) that refuse disposal areas are removed from row-crop production.

Property values

Reduced land values associated with reclaimed mine refuse areas results in lowered market value and assessed tax value. To demonstrate the magnitude of the change, an approximate true market value for the 3,844 acres needed for present and future disposal was obtained by conversion of the average assessed tax value (Table 14) (which reflects only one third of the market value). A significant decrease in the market value of the land occurs if a reclamation alternative of limited productivity is chosen. A $2,710,000 market value for cropland is reduced to $1,084,008 for the wildlife habitat reclamation alternative, or $1,626,012 for pasture reclamation. Also, as cropland continues to increase in value, the differential in property values will assume even greater economic significance.

The environmental quality of an area can influence the market value of nearby property (Epp and Al-Ani 1978). Although values of property adjacent to coal refuse sites may be depressed, the degree to which values are lowered depends upon the reclamation effort (Ballou 1976). According to Clapper and Wilkey (1978), residential property near an abandoned refuse site in Illinois increased 500 percent in value after reclamation. As reclamation at active mines must be kept current (P.L. 95-87), entire refuse sites must be revegetated 1 year after the mine closes. Hence, values of property adjacent to active refuse sites may not increase so dramatically after final reclamation as for those properties near previously abandoned sites.

Although no active mines in Illinois are located in densely populated areas, most are near rural residences. A measure of the amount which property values are depressed can be obtained by using an estimate of 1 acre of land per home and conservative difference of 100 percent between pre and post reclamation values. Prices of rural residential land can vary widely; but, according to values provided by county Supervisors of Assessment, $1000 per acre would represent an average price. There are approximately 116 rural residences within 1/4 miles of active refuse sites in Illinois. Using the parameters specified above, the presence of refuse sites may be depressing the market value of these 116 residences by as much as $116,000. With an average county tax rate of .0489 percent (Illinois Department Local Government Affairs 1978), the devaluation of property could be costing affected counties $5,672 annually.

In summary, utilization of land for refuse disposal does affect the productivity and assessed value of the land, although the acres and monies involved are not excessively large. Adjacent land values may also be affected, but again, the monies involved are not large. The fact remains

that current surface disposal does continue to effect the land, and that potential environmental problems could occur if the protective plant and soil cover were disturbed. Consequently, possible alternatives to the current practices of surface disposal of mine refuse should be examined.

Alternative Refuse Disposal Techniques

Coal mine refuse associated with underground mines in Illinois is usually deposited in surface piles and impoundments; where convenient refuse may be buried in surface mine final cuts and inclines. Although current reclamation requirements insure that disposal areas are covered (four feet of soil) and contained to prevent the development of pollutional problems, the steep slopes and limited soil cover could be subject to erosion if the vegetative cover was disturbed by an incompatible land use. Over-grazing, tilling and utilization by off-road vehicles are examples of uses that could disturb the protective soil cover. Alternatives to surface disposal of underground coal refuse could include secondary utilization of the refuse materials and underground disposal. Both alternatives would minimize reclamation efforts needed for disposal sites and substantially reduce associated environmental and land use problems.

Utilization of coal refuse has included landfill and road surface materials; older disposal sites have been mined for carbon left by less discriminate coal processing techniques of old mines (National Academy of Sciences 1975). Other alternatives include the use of refuse as aggregate and construction materials, and the recovery of

minerals and trace elements (e.g., aluminum, zinc, sulphur); however, these uses are generally uneconomical except in certain site-specific circumstances (Falkie 1974, Cobb et al. 1979).

During the 1950's and 1960's, underground disposal, or backfilling, of refuse into active mines was commonly practiced in Europe. Hydraulic and pneumatic devices transported wastes into the mine to minimize subsidence, thereby allowing more complete removal of coal by longwall mining. With recent changes in mining technology, practices and economics, backfilling in European mines has declined and is used only when mining under major rivers, cities and densely populated areas where subsidence problems would be severe (Fairhurst 1974). Generally, backfilling has not been considered economically feasible in the U.S. There has been limited effort, largely experimental, to dispose of wastes in underground mines to control subsidence.

A review of the benefits and liabilities of backfilling (Falkie 1974) suggested that underground disposal would prevent air and water pollution as well as remove a potential hazard to public health, an aesthetic blight, and an inhibition to community development. Underground disposal might aid in control of subsidence as well as give additional support allowing increased coal tonnage removed. Certain safety aspects could be enhanced, such as the prevention of water and sediment infiltration from overlying aquifers, the reduction of gas accumulation, the loss of ventilation air, and the possibility of spontaneous combustion (Falkie 1974). Of particular benefit to the Midwest, especially Illinois, would be the preservation of productive agricultural land that would otherwise be lost due to surface area impaction by refuse.

The major disadvantages of underground disposal lie in attempting to integrate production activities with the backfilling operations, without unduely reducing productivity or increasing production costs. Underground disposal would interfere with the multi-shift, highly mechanized methods of mining that provide the competitive edge for most mining companies (Falkie 1974). Problems include transporting waste into the mine, keeping waste materials out of the working area, and the need for extra labor. Hydraulic backfilling of refuse materials may result in acid intrusion into the water table. The health and safety of miners could be adversely affected as more workers would be exposed to the hazards of working underground. In addition, pneumatic backfilling could increase the levels of airborne dust and noise.

In conclusion, until the logistical, technical, and safety problems associated with alternate disposal practices are resolved through research, and the land use, economic, political and legal pressures change, surface disposal will remain the major form of mine refuse disposal for underground mines.

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